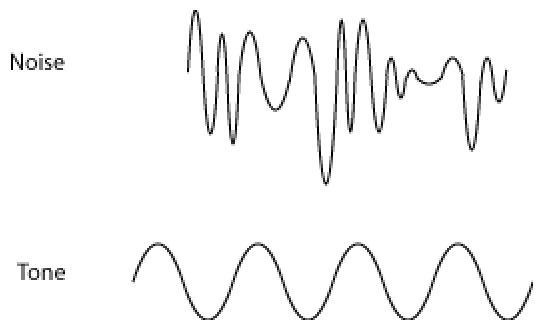
Acoustics for Music Theory
For adults, a short review of the physics underlying music theory.

Music is Organized Sound Waves

Music is sound that's organized by people on purpose, to dance to, to tell a story, to make other people feel a certain way, or just to sound pretty or be entertaining. Music is organized on many different levels. Sounds can be arranged into melodies, harmonies, rhythms, textures and phrases. Beats, measures, cadences, and form all help to keep the music organized and understandable. But the most basic way that music is organized is by arranging the actual sound waves themselves so that the sounds are interesting and pleasant and go well together.

A rhythmic, organized set of thuds and crashes is perfectly good music - think of your favorite drum solo - but many musical instruments are designed specifically to produce the regular, evenly spaced sound waves that we hear as particular pitches. Crashes, thuds, and bangs are loud, short jumbles of lots of different wavelengths. These are the kinds of sound we often call "noise", when they're random and disorganized, but as soon as they are organized in time (rhythm), they begin to sound like music. (When used as a scientific term, **noise** refers to **continuous** sounds that are random mixtures of different wavelengths, not shorter crashes and thuds.)

However, to get the melodic kind of sounds more often associated with music, the sound waves must themselves be organized and regular, not random mixtures. Most of the sounds we hear are brought to our ears through the air. A movement of an object causes a disturbance of the normal motion of the air molecules near the object. Those molecules in turn disturb other nearby molecules out of their normal patterns of random motion, so that the disturbance itself becomes a thing that moves through the air - a sound wave. If the movement of the object is a fast, regular vibration, then the sound waves are also very regular. We hear such regular sound waves as **tones**, sounds with a particular pitch. It is this kind of sound that we most often associate with music, and that many musical instruments are designed to make.



A random jumble of sound waves is heard as a noise. A regular, evenly-spaced sound wave is heard as a tone.

Musicians have terms that they use to describe tones. (Musicians also have other meanings for the word "tone", but this course will stick to the "a sound with pitch" meaning.) This kind of (regular, evenly spaced) wave is useful for things other than music, however, so scientists and engineers also have terms that describe pitched sound waves. As we talk about where music theory comes from, it will be very useful to know both the scientific and the musical terms and how they are related to each other.

For example, the closer together those evenly-spaced waves are, the higher the note sounds. Musicians talk about the pitch of the sound, or name specific notes, or talk about tuning. Scientists and engineers, on the other hand, talk about the frequency and the wavelength of the sound. They are all essentially talking about the same things, but talking about them in slightly different ways, and using the scientific ideas of wavelength and frequency can help clarify some of the main ideas underlying music theory.

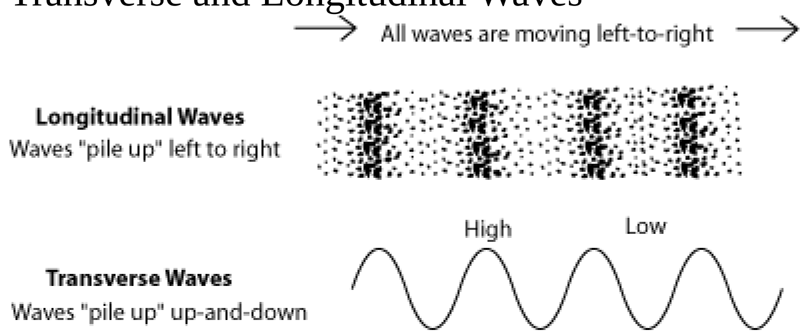
Longitudinal and Transverse Waves

So what are we talking about when we speak of sound waves? Waves are disturbances; they are changes in something - the surface of the ocean, the air, electromagnetic fields. Normally, these changes are travelling (except

for standing waves); the disturbance is moving away from whatever created it, in a kind of domino effect.

Most kinds of waves are **transverse** waves. In a transverse wave, as the wave is moving in one direction, it is creating a disturbance in a different direction. The most familiar example of this is waves on the surface of water. As the wave travels in one direction - say south - it is creating an up-and-down (not north-and-south) motion on the water's surface. This kind of wave is fairly easy to draw; a line going from left-to-right has up-and-down wiggles. (See [link].)

Transverse and Longitudinal Waves



In water waves and other **transverse waves**, the ups and downs are in a different direction from the forward movement of the wave. The "highs and lows" of sound waves and other **longitudinal waves** are arranged in the "forward" direction.

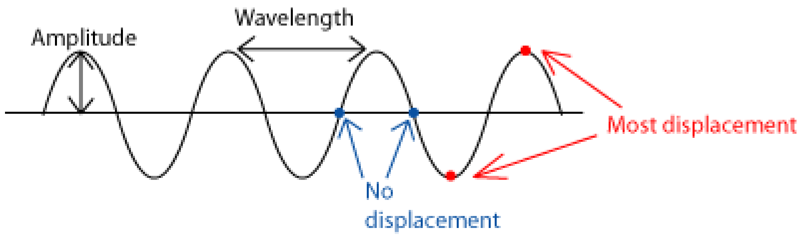
But sound waves are not transverse. Sound waves are **longitudinal waves**. If sound waves are moving south, the disturbance that they are creating is giving the air molecules extra north-and-south (not east-and-west, or up-and-down) motion. If the disturbance is from a regular vibration, the result is that the molecules end up squeezed together into evenly-spaced waves. This is very difficult to show clearly in a diagram, so **most diagrams, even diagrams of sound waves, show transverse waves**.

Longitudinal waves may also be a little difficult to imagine, because there aren't any examples that we can see in everyday life (unless you like to play with toy slinkies). A mathematical description might be that in longitudinal waves, the waves (the disturbances) are along the same axis as the direction of motion of the wave; transverse waves are at right angles to the direction of motion of the wave. If this doesn't help, try imagining yourself as one of the particles that the wave is disturbing (a water drop on the surface of the ocean, or an air molecule). As it comes from behind you, a transverse waves lifts you up and then drops down; a longitudinal wave coming from behind pushes you forward and pulls you back. You can view here animations of longitudinal and transverse waves, single particles being disturbed by a transverse wave or by a longitudinal wave, and particles being disturbed by transverse and longitudinal waves.

The result of these "forward and backward" waves is that the "high point" of a sound wave is where the air molecules are bunched together, and the "low point" is where there are fewer air molecules. In a pitched sound, these areas of bunched molecules are very evenly spaced. In fact, they are so even, that there are some very useful things we can measure and say about them. **In order to clearly show you what they are, most of the diagrams in this course will show sound waves as if they are transverse waves**.

Wave Amplitude and Loudness

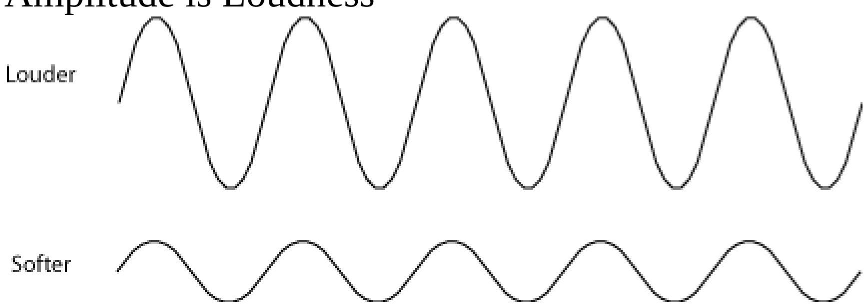
Both transverse and longitudinal waves cause a **displacement** of something: air molecules, for example, or the surface of the ocean. The amount of displacement at any particular spot changes as the wave passes. If there is no wave, or if the spot is in the same state it would be in if there was no wave, there is no displacement. Displacement is biggest (furthest from "normal") at the highest and lowest points of the wave. In a sound wave, then, there is no displacement wherever the air molecules are at a normal density. The most displacement occurs wherever the molecules are the most crowded or least crowded.
Displacement



The **amplitude** of the wave is a measure of the displacement: how big is the change from no displacement to the peak of a wave? Are the waves on the lake two inches high or two feet? Are the air molecules bunched very tightly together, with very empty spaces between the waves, or are they barely more organized than they would be in their normal course of bouncing off of each other? Scientists measure the amplitude of sound waves in **decibels**. Leaves rustling in the wind are about 10 decibels; a jet engine is about 120 decibels.

Musicians call the loudness of a note its **dynamic level**. **Forte** (pronounced "FOR-tay") is a loud dynamic level; **piano** is soft. Dynamic levels don't correspond to a measured decibel level. An orchestra playing "fortissimo" (which basically means "even louder than forte") is going to be quite a bit louder than a string quartet playing "fortissimo". (See Dynamics for more of the terms that musicians use to talk about loudness.) Dynamics are more of a performance issue than a music theory issue, so amplitude doesn't need much discussion here.

Amplitude is Loudness



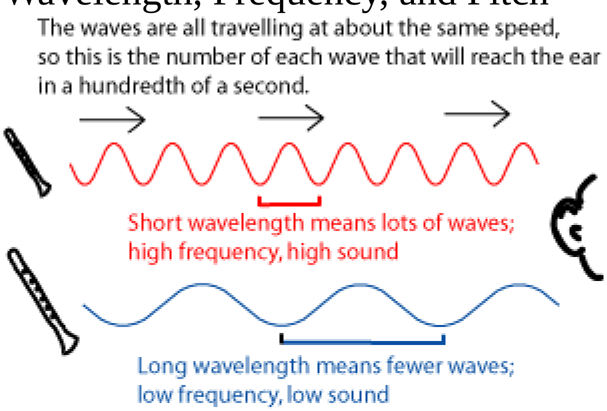
The size of a wave (how much it is "piled up" at the high points) is its **amplitude**. For sound waves, the bigger the amplitude, the louder the sound.

Wavelength, Frequency, and Pitch

The aspect of evenly-spaced sound waves that really affects music theory is the spacing between the waves, the distance between, for example, one high point and the next high point. This is the **wavelength**, and it affects the pitch of the sound; the closer together the waves are, the higher the tone sounds.

All sound waves are travelling at about the same speed - the speed of sound. So waves with a shorter wavelength arrive (at your ear, for example) more often (frequently) than longer waves. This aspect of a sound - how often a peak of a wave goes by, is called **frequency** by scientists and engineers. They measure it in **hertz**, which is how many peaks go by per second. People can hear sounds that range from about 20 to about 17,000 hertz.

Wavelength, Frequency, and Pitch



Since the sounds are travelling at about the same speed, the one with the shorter wavelength "waves" more frequently; it has a higher frequency, or pitch. In other words, it sounds higher.

The word that musicians use for frequency is **pitch**. The shorter the wavelength, the higher the frequency, and the higher the pitch, of the sound. In other words, short waves sound high; long waves sound low. Instead of

measuring frequencies, musicians name the pitches that they use most often. They might call a note "middle C" or "second line G" or "the F sharp in the bass clef". (See Octaves and Diatonic Music and Tuning Systems for more on naming specific frequencies.) These notes have frequencies (Have you heard of the "A 440" that is used as a tuning note?), but the actual frequency of a middle C can vary a little from one orchestra, piano, or performance, to another, so musicians usually find it more useful to talk about note names.

Most musicians cannot name the frequencies of any notes other than the tuning A (440 hertz). The human ear can easily distinguish two pitches that are only one hertz apart when it hears them both, but it is the very rare musician who can hear specifically that a note is 442 hertz rather than 440. So why should we bother talking about frequency, when musicians usually don't? As we will see, the physics of sound waves - and especially frequency - affects the most basic aspects of music, including pitch, tuning, consonance and dissonance, harmony, and timbre.

Standing Waves and Wind Instruments
The musical sounds of aerophones (woodwinds and brass) are created by standing waves in the air inside the instruments.

Introduction

A wind instrument makes a tone when a standing wave of air is created inside it. In most wind instruments, a vibration that the player makes at the mouthpiece is picked up and amplified and given a pleasant timbre by the air inside the tube-shaped body of the instrument. The shape and length of the inside of the tube give the sound wave its pitch as well as its timbre.

You will find below a discussion of what makes standing waves in a tube, wind instruments and the harmonic series, and the types of tubes that can be used in musical instruments. This is a simplified discussion to give you a basic idea of what's going on inside a wind instrument. Mathematical equations are avoided, and all the complications - for example, what happens to the wave when there are closed finger holes in the side of the tube - are ignored. Actually, the physics of what happens inside real wind instruments is so complex that physicists are still studying it, and still don't have all the answers. If you want a more in-depth or more technical discussion, there are some recommendations below.

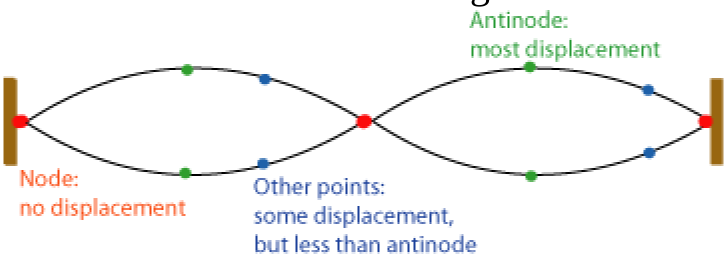
If you can't follow the discussion below, try reviewing Acoustics for Music Theory, Standing Waves and Musical Instruments, Harmonic Series I, and Wind Instruments: Some Basics

What Makes the Standing Waves in a Tube

As discussed in Standing Waves and Musical Instruments, instruments produce musical tones by trapping waves of specific lengths in the instrument. It's pretty easy to see why the standing waves on a string can only have certain lengths; since the ends of the strings are held in place, there has to be a node in the wave at each end. But what is it that makes only certain standing waves possible in a tube of air?

To understand that, you'll have to understand a little bit about what makes waves in a tube different from waves on a string. Waves on a string are transverse waves. The string is stretched out in one direction (call it "up and down"), but when it's vibrating, the motion of the string is in a different direction (call it "back and forth"). Take a look at this animation. At the nodes (each end, for example), there is no back and forth motion, but in between the nodes, the string is moving back and forth very rapidly. The term for this back-and-forth motion is **displacement**. There is no displacement at a node; the most displacement happens at an antinode.

Transverse Motion on a String



The standing waves of air in a tube are not transverse waves. Like all sound waves, they are longitudinal. So if the air in the tube is moving in a certain direction (call it "left and right"), the vibrations in the air are going in that same direction (in this case, they are rushing "left and right").

But they are like the waves on a string in some important ways. Since they are standing waves, there are still nodes - in this case, places where the air is not rushing back and forth. And, just as on the string, in between the nodes there are antinodes, where the displacement is largest (the air is moving back and forth the most). And when one antinode is going in one direction (left), the antinodes nearest it will be going in the other direction (right). So, even though what is happening is very different, the end result of standing waves "trapped" in a tube will be very much like the end result of standing waves "trapped" on a string: a harmonic series based on the tube length.

There will be more on that harmonic series in the next section. First, let's talk about why only some standing waves will "fit" in a tube of a particular length. If the tube were closed on both ends, it's easy to see that this would be a lot like the wave on the string. The air would not be able to rush back

and forth at the ends, so any wave trapped inside this tube would have to have nodes at each end.

Note: It's very difficult to draw air that is rushing back and forth in some places and standing still in other places, so most of the figures below use a common illustration method, showing the longitudinal waves as if they are simultaneously the two maximum positions of a transverse wave. Here is an animation that may give you some idea of what is happening in a longitudinal standing wave. As of this writing, there was a nice Standing Waves applet demonstration of waves in tubes. Also, see below for more explanation of what the transverse waves inside the tubes really represent.

Fully Closed Tube

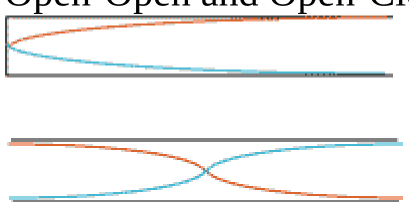
The standing waves inside the tube represent back-and-forth motion of the air. Since the air can't move through the end of the tube, a closed tube must have a node at each end, just like a string held at both ends.

Now, a closed tube wouldn't make a very good musical instrument; it wouldn't be very loud. Most of the sound you hear from an instrument is

not the standing wave inside the tube; the sound is made at the open ends where the standing waves manage to create other waves that can move away from the instrument. Physicists sometimes study the acoustics of a tube closed at both ends (called a **Kundt tube**), but most wind instruments have at least one open end. An instrument that is open at both ends may be called **open-open**, or just an **open tube** instrument. An instrument that is only open at one end may be called **open-closed**, or a **closed tube** or **stopped tube** instrument (or sometimes **semi-closed** or **half-closed**). This is a little confusing, since such instruments (trumpets, for example) still obviously have one open end.

Now, there's nothing stopping the air from rushing back and forth at the open end of the tube. In fact, the waves that "fit" the tube are the ones that have antinodes at the open end, so the air is in fact rushing back and forth there, causing waves (at the same frequency as the standing wave) that are not trapped in the instrument but can go out into the room.

Open-Open and Open-Closed Tubes

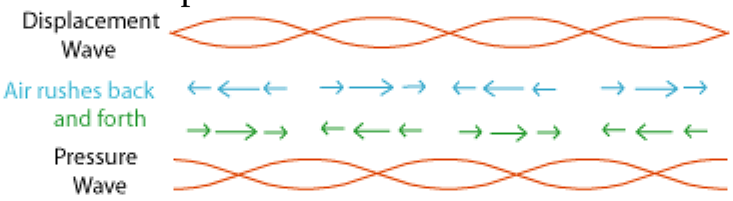


There must be a (displacement) antinode at any open end of a tube.

What is it that requires the waves to have an antinode at an open end? Look again at the animation of what is happening to the air particles in the standing wave. The air at the nodes is not moving back and forth, but it is piling up and spreading out again. So the **air pressure** is changing a lot at the nodes. But at the antinodes, the air is moving a lot, but it is moving back and forth, not piling up and spreading out. In fact, you can imagine that same wave to be an air pressure wave instead of an air displacement wave. It really is both at the same time, but the pressure wave nodes are at the

same place as the displacement antinodes, and the pressure antinodes are at the same place as the displacement nodes.

An Air Displacement Wave is also an Air Pressure Wave



The nodes of the displacement wave, where the air is not rushing back-and-forth but is doing the most piling-up-and-spreading-out, are the antinodes of the pressure wave. The antinodes of the displacement wave, where the air is rushing back-and-forth the most, but is not piling up or spreading out at all, are the nodes of the pressure wave. Both waves must have exactly the same frequency, of course; they are actually just two aspects of the same sound wave.

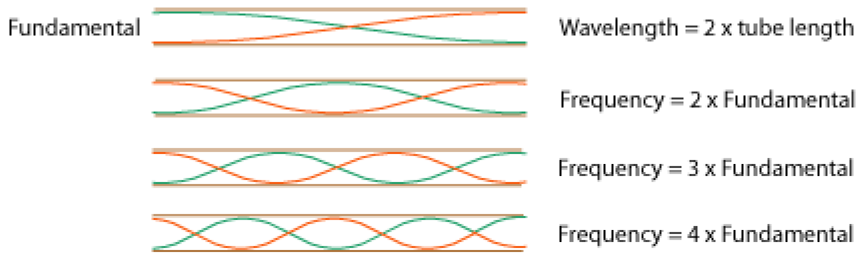
At an open end of the tube, there is nothing to stop the air rushing in and out, and so it does. What the air cannot do at the open end is build up any pressure; there is nothing for the air to build up against, and any drop in pressure will just bring air rushing in from outside the tube. So the air pressure at an open end must remain the same as the air pressure of the room. In other words, that end must have a pressure node (where the air pressure doesn't change) and (therefore) a displacement antinode.

Note: Since being exposed to the air pressure outside the instrument is what is important, the "open end" of a wind instrument, as far as the sound waves are concerned, is the first place that they can escape - the first open hole. This is how woodwinds change the length of the wave, and the pitch of the note. For more on this, please see Wind Instruments – Some Basics.

Harmonic Series in Tubes

As explained in the previous section, the standing waves in a tube must have a (displacement) node at a closed end and an antinode at an open end. In an open-open tube, this leads to a harmonic series very similar to a harmonic series produced on a string that's held at both ends. The **fundamental**, the lowest note possible in the tube, is the note with a wavelength twice the length of the tube (or string). The next possible note has twice the frequency (half the wavelength) of the fundamental, the next three times the frequency, the next four times, and so on.

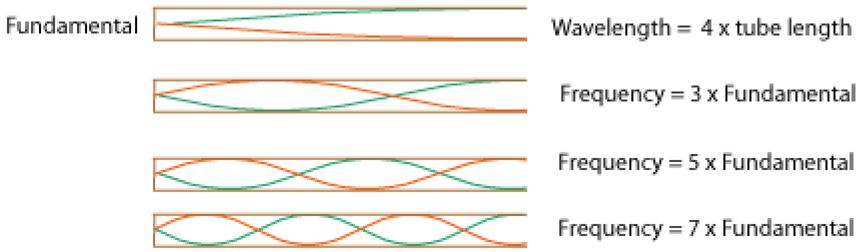
Allowed Waves in an Open Tube



These are the first four harmonics allowed in an open tube. Any standing wave with a displacement antinode at both ends is allowed, but the lower harmonics are usually the easiest to play and the strongest harmonics in the timbre.

But things are a little different for the tube that is closed at one end and open at the other. The lowest note that you might be able to get on such a tube (a fundamental that is unplayable on many instruments) has a wavelength four times the length of the tube. (You may notice that this means that a stopped tube will get a note half the frequency - an octave lower - than an open tube of the same length.) The next note that is possible on the half-closed tube has three times the frequency of the fundamental, the next five times,and so on. In other words, a stopped tube can only play the odd-numbered harmonics.

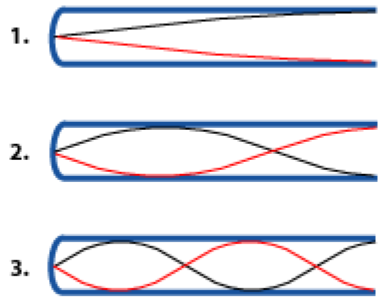
Allowed Wavelengths in a Stopped Tube



Again, these are the lowest (lowest pitch and lowest frequency) four harmonics allowed. Any wave with a displacement node at the closed end and antinode at the open end is allowed. Note that this means only the odd-numbered harmonics "fit".

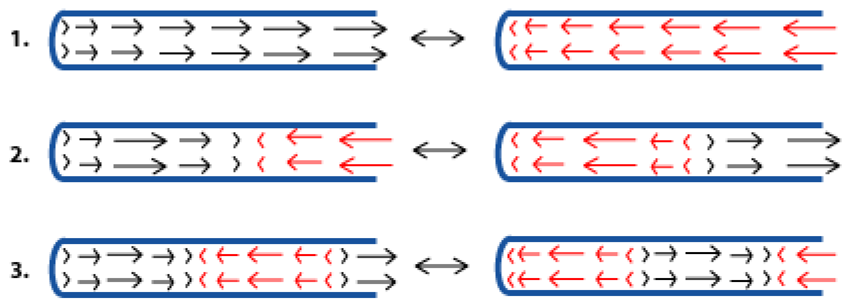
Note: All of the transverse waves in [link], [link], [link], and [link] represent longitudinal displacement waves, as shown in [link]. All of the harmonics would be happening in the tube at the same time, and, for each harmonic, the displacement ([link]) and pressure waves ([link]) are just two different ways of representing the same wave.

Displacement Waves



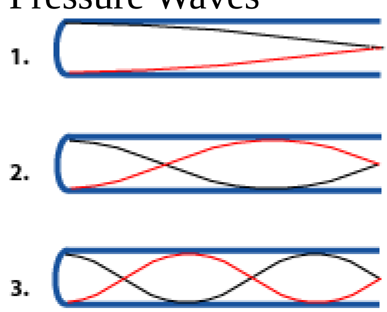
Transverse standing waves shown inside tubes actually represent movement back and forth between two extremes.
Usually, nodes are shown at closed ends and antinodes at open ends. This represents the air displacement waves; the air cannot move back and forth through the closed end, but it is free to rush back and forth through the open tube end..

The three transverse waves above, for example, represent air movement that goes back and forth between the state on the left and the state on the right (the shorter the arrow, the less the air in that area is moving) :

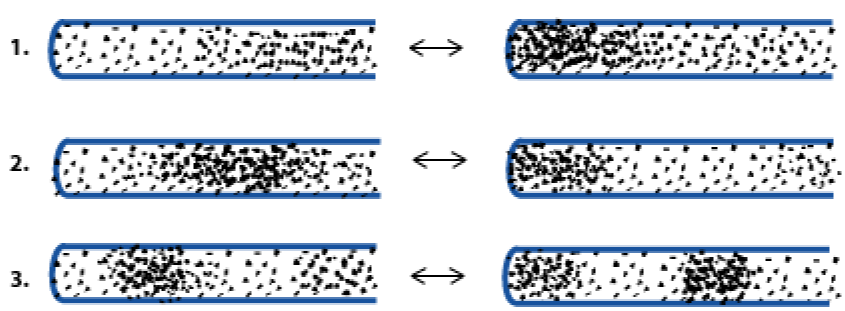


Here are the first three possible harmonics in a closed-open tube shown as longitudinal displacement waves.

Pressure Waves



If you consider the standing waves as pressure waves rather than displacement waves, the nodes would be at the open end! This is because it is easy to change the pressure at a closed end, but impossible to change it at an open end. Pressure at an open end will always be room pressure, so standing pressure waves alternate between high and low pressure at closed ends.



Here are those same three waves shown as pressure waves.

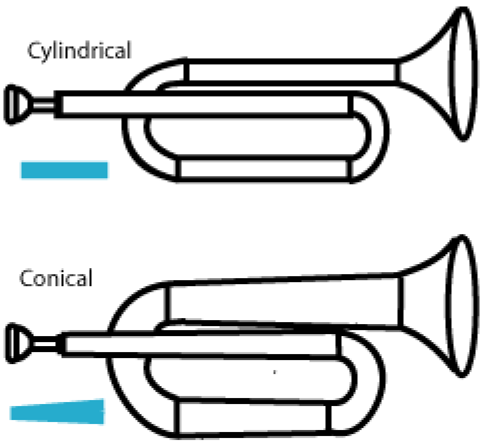
Basic Wind Instrument Tube Types

The previous section shows why only the odd-numbered harmonics "fit" in a cylinder-shaped tube, but that is not the whole story. There is one other tube shape that works well for wind instruments, and it abides by slightly different rules.

Just as on a string, the actual wave inside the instrument is a complex wave that includes all of those possible harmonics. A cylinder makes a good musical instrument because all the waves in the tube happen to have simple, harmonic-series-type relationships. This becomes very useful when the player **overblows** in order to get more notes. As mentioned above, woodwind players get different notes out of their instruments by opening and closing finger holes, making the standing wave tube longer or shorter. Once the player has used all the holes, higher notes are played by **overblowing**, which causes the next higher harmonic of the tube to sound. In other words, the fundamental of the tube is not heard when the player "overblows"; the note heard is the pitch of the next available harmonic (either harmonic two or three). Brass players can get many different harmonics from their instruments, and so do not need as many fingerings. (Please see Harmonic Series and Wind Instruments – Some Basics for more on this.)

For most possible tube shapes, a new set of holes would be needed to get notes that are in tune with the lower set of notes. But a couple of shapes, including the cylinder, give higher notes that are basically in tune with the lower notes using the same finger holes (or valves). (Even so, some extra finger holes or an extra slide or valve is sometimes necessary for good tuning.) One other possible shape is basically not used because it would be difficult to build precisely and unwieldy to play. (Basically, it has to flare rapidly, at a very specific rate of flare. The resulting instrument would be

unwieldy and impractical. Please see John S. Rigden's *Physics and the Sound of Music*, as cited below for more on this.)



The two shapes that are useful for real wind instruments are the cylinder and the cone. Most real wind instruments are a combination of cylindrical and conical sections, but most act as (and can be classified as) either **cylindrical bore** or **conical bore** instruments.

The other tube shape that is often used in wind instruments is the cone. In fact, most real wind instruments are tubes that are some sort of combination of cylindrical and conical tubes. But most can be classified as either cylindrical or conical instruments.

The really surprising thing is that stopped-tube instruments that are basically conical act as if they are open-tube cylindrical instruments.

Note: The math showing why this happens has been done, but I will not go into it here. Please see the further reading, below for books with a more rigorous and in-depth discussion of the subject.

Compare, for example, the clarinet and the saxophone, woodwinds with very similar mouthpieces. Both instruments, like any basic woodwind, have enough finger holes and keys to play all the notes within an octave. To get more notes, a woodwind player **overblows**, blowing hard enough to sound the next harmonic of the instrument. For the saxophone, a very conical instrument, the next harmonic is the next octave (two times the frequency of the fundamental), and the saxophonist can continue up this next octave by essentially repeating the fingerings for the first octave. Only a few extra keys are needed to help with tuning.

The clarinet player doesn't have it so easy. Because the clarinet is a very cylindrical instrument, the next harmonic available is three times the frequency, or an octave and a fifth higher, than the fundamental. Extra holes and keys have to be added to the instrument to get the notes in that missing fifth, and then even more keys are added to help the clarinetist get around the awkward fingerings that can ensue. Many notes have several possible fingerings, and the player must choose fingerings based on tuning and ease of motion as they change notes.

So why bother with cylindrical instruments? Remember that an actual note from any instrument is a very complex sound wave that includes lots of harmonics. The pitch that we hear when a wind instrument plays a note is (usually) the lowest harmonic that is being produced in the tube at the time. The higher harmonics produce the timbre, or sound color, of the instrument. A saxophone-shaped instrument simply can't get that odd-harmonics clarinet sound.

The shapes and sounds of the instruments that are popular today are the result of centuries of trial-and-error experimentation by instrument-makers. Some of them understood something of the physics involved, but the actual physics of real instruments - once you add sound holes, valves, keys, mouthpieces, and bells - are incredibly complex, and theoretical physicists are still studying the subject and making new discoveries.

Further Reading

- Alexander Wood's *The Physics of Music* (1944, The Sherwood Press) is a classic which includes both the basics of waves in a pipe and information about specific instruments.
- John Backus' *The Acoustical Foundations of Music* (1969, W.W. Norton and Company) also goes into more detail on the physics of specific instruments.
- John S. Rigden's *Physics and the Sound of Music* (1977, John Wiley and Sons) includes most of the math necessary for a really rigorous, complete explanation of basic acoustics, but is (in my opinion) still very readable.
- Arthur H. Benade's *Fundamentals of Musical Acoustics* is a more technical textbook that gives some idea of how acoustical experiments on instruments are designed and carried out. Those who are less comfortable with the science/engineering aspect of the subject may prefer the two very thorough articles by Benade in:
- *The Physics of Music* (W. H. Freeman and Co.), a collection of readings from the periodical *Scientific American*.

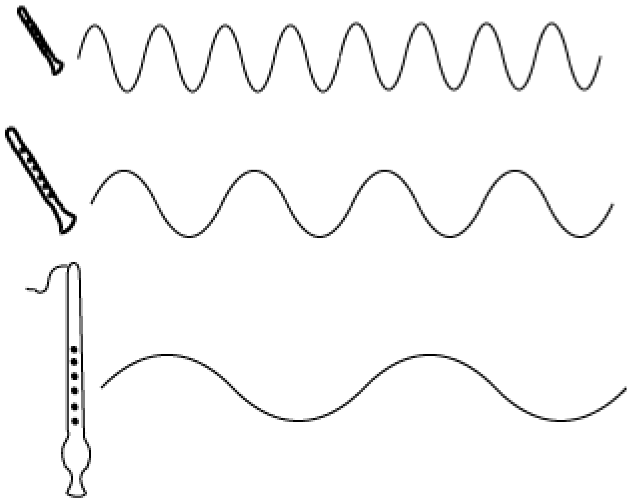
Harmonic Series
The harmonic series is the key to understanding not only harmonics, but also timbre and the basic functioning of many musical instruments.

Introduction

Have you ever wondered how a trumpet plays so many different notes with only three valves, or how a bugle plays different notes with no valves at all? Have you ever wondered why an oboe and a flute sound so different, even when they're playing the same note? What is a string player doing when she plays "harmonics"? Why do some notes sound good together while other notes seem to clash with each other? The answers to all of these questions will become clear with an understanding of the harmonic series.

Physics, Harmonics and Color

Most musical notes are sounds that have a particular pitch. The pitch depends on the main frequency of the sound; the higher the frequency, and shorter the wavelength, of the sound waves, the higher the pitch is. But musical sounds don't have just one frequency. Sounds that have only one frequency are not very interesting or pretty. They have no more musical color than the beeping of a watch alarm. On the other hand, sounds that have too many frequencies, like the sound of glass breaking or of ocean waves crashing on a beach, may be interesting and even pleasant. But they don't have a particular pitch, so they usually aren't considered musical notes.
Frequency and Pitch



The higher the frequency, the
higher the note sounds.

When someone plays or sings a note, only a very particular set of frequencies is heard. Imagine that each note that comes out of the instrument is a smooth mixture of many different pitches. These different pitches are called **harmonics**, and they are blended together so well that you do not hear them as separate notes at all. Instead, the harmonics give the note its color.

What is the color of a sound? Say an oboe plays a middle C. Then a flute plays the same note at the same loudness as the oboe. It is still easy to tell the two notes apart, because an oboe sounds different from a flute. This difference in the sounds is the **color**, or **timbre** (pronounced "TAM-ber") of the notes. Like a color you see, the color of a sound can be bright and bold or deep and rich. It can be heavy, light, murky, thin, smooth, or transparently clear. Some other words that musicians use to describe the timbre of a sound are: reedy, brassy, piercing, mellow, thin, hollow, focussed, breathy (pronounced BRETH-ee) or full. Listen to recordings of a violin and a viola. Although these instruments are quite similar, the viola has a noticeably "deeper" and the violin a noticeably "brighter" sound that is not simply a matter of the violin playing higher notes. Now listen to the same phrase played by an electric guitar, an acoustic guitar with twelve

steel strings and an acoustic guitar with six nylon strings. The words musicians use to describe timbre are somewhat subjective, but most musicians would agree with the statement that, compared with each other, the first sound is mellow, the second bright, and the third rich.

Exercise:

Problem:

Listen to recordings of different instruments playing alone or playing very prominently above a group. Some suggestions: an unaccompanied violin or cello sonata, a flute, oboe, trumpet, or horn concerto, native American flute music, classical guitar, bagpipes, steel pan drums, panpipes, or organ. For each instrument, what "color" words would you use to describe the timbre of each instrument? Use as many words as you can that seem appropriate, and try to think of some that aren't listed above. Do any of the instruments actually make you think of specific shades of color, like fire-engine red or sky blue?

Solution:

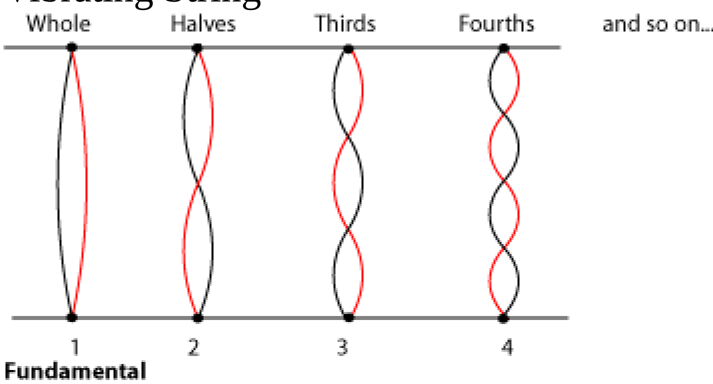
Although trained musicians will generally agree that a particular sound is reedy, thin, or full, there are no hard-and-fast right-and-wrong answers to this exercise.

Where do the harmonics, and the timbre, come from? When a string vibrates, the main pitch you hear is from the vibration of the whole string back and forth. That is the **fundamental**, or first harmonic. But the string also vibrates in halves, in thirds, fourths, and so on. Each of these fractions also produces a harmonic. The string vibrating in halves produces the second harmonic; vibrating in thirds produces the third harmonic, and so on.

Note: This method of naming and numbering harmonics is the most straightforward and least confusing, but there are other ways of naming and numbering harmonics, and this can cause confusion. Some musicians do not consider the fundamental to be a harmonic; it is just the

fundamental. In that case, the string halves will give the first harmonic, the string thirds will give the second harmonic and so on. When the fundamental is included in calculations, it is called the first **partial**, and the rest of the harmonics are the second, third, fourth partials and so on. Also, some musicians use the term **overtones** as a synonym for harmonics. For others, however, an overtone is any frequency (not necessarily a harmonic) that can be heard resonating with the fundamental. The sound of a gong or cymbals will include overtones that aren't harmonics; that's why the gong's sound doesn't seem to have as definite a pitch as the vibrating string does. If you are uncertain what someone means by the second harmonic or by the term overtones, ask for clarification.

Vibrating String



The fundamental pitch is produced by the whole string vibrating back and forth. But the string is also vibrating in halves, thirds, quarters, fifths, and so on, producing **harmonics**. All of these vibrations happen at the same time, producing a rich, complex, interesting sound.

A column of air vibrating inside a tube is different from a vibrating string, but the column of air can also vibrate in halves, thirds, fourths, and so on, of

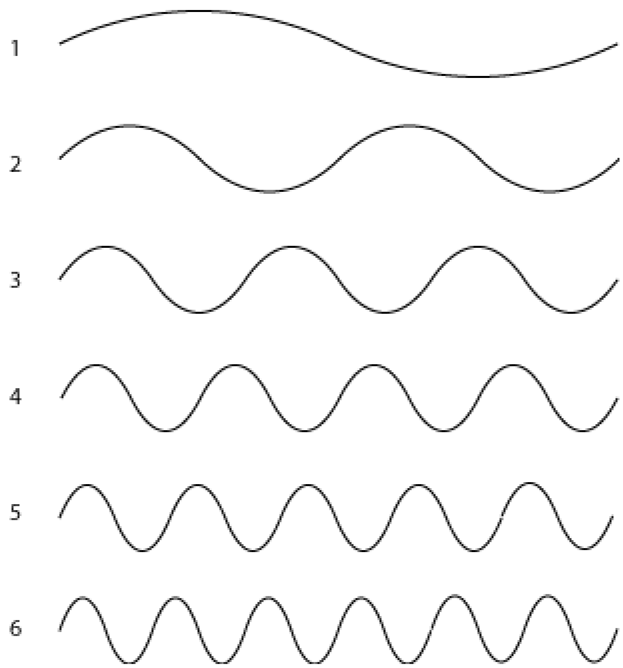
the fundamental, so the harmonic series will be the same. So why do different instruments have different timbres? The difference is the relative loudness of all the different harmonics compared to each other. When a clarinet plays a note, perhaps the odd-numbered harmonics are strongest; when a French horn plays the same notes, perhaps the fifth and tenth harmonics are the strongest. This is what you hear that allows you to recognize that it is a clarinet or horn that is playing.

Note: You will find some more extensive information on instruments and harmonics in Standing Waves and Musical Instruments and Standing Waves and Wind Instruments.

The Harmonic Series

A harmonic series can have any note as its fundamental, so there are many different harmonic series. But the relationship between the frequencies of a harmonic series is always the same. The second harmonic always has exactly half the wavelength (and twice the frequency) of the fundamental; the third harmonic always has exactly a third of the wavelength (and so three times the frequency) of the fundamental, and so on. For more discussion of wavelengths and frequencies, see Frequency, Wavelength, and Pitch.

Harmonic Series Wavelengths and Frequencies



The second harmonic has half the wavelength and twice the frequency of the first. The third harmonic has a third the wavelength and three times the frequency of the first. The fourth harmonic has a quarter the wavelength and four times the frequency of the first, and so on. Notice that the fourth harmonic is also twice the frequency of the second harmonic, and the sixth harmonic is also twice the frequency of the third harmonic.

Say someone plays a note, a middle C. Now someone else plays the note that is twice the frequency of the middle C. Since this second note was already a harmonic of the first note, the sound waves of the two notes reinforce each other and sound good together. If the second person played instead the note that was just a litle bit more than twice the frequency of the

first note, the harmonic series of the two notes would not fit together at all, and the two notes would not sound as good together. There are many combinations of notes that share some harmonics and make a pleasant sound together. They are considered consonant. Other combinations share fewer or no harmonics and are considered dissonant or, when they really clash, simply "out of tune" with each other. The scales and chords of most of the world's musics are based on these physical facts.

Note: In real music, consonance and dissonance also depend on the standard practices of a musical tradition, especially its harmony practices, but these are also often related to the harmonic series.

For example, a note that is twice the frequency of another note is one octave higher than the first note. So in the figure above, the second harmonic is one octave higher than the first; the fourth harmonic is one octave higher than the second; and the sixth harmonic is one octave higher than the third.

Exercise:

Problem:

1. Which harmonic will be one octave higher than the fourth harmonic?
2. Predict the next four sets of octaves in a harmonic series.
3. What is the pattern that predicts which notes of a harmonic series will be one octave apart?
4. Notes one octave apart are given the same name. So if the first harmonic is a "A", the second and fourth will also be A's. Name three other harmonics that will also be A's.

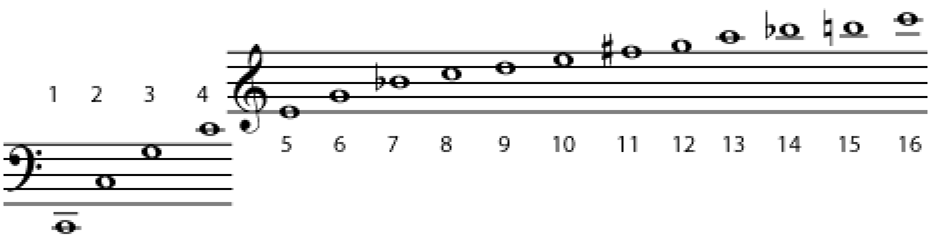
Solution:

1. The eighth harmonic
2. The fifth and tenth harmonics; the sixth and twelfth harmonics; the seventh and fourteenth harmonics; and the eighth and

sixteenth harmonics
3. The note that is one octave higher than a harmonic is also a harmonic, and its number in the harmonic series is twice (2 X) the number of the first note.
4. The eighth, sixteenth, and thirty-second harmonics will also be A's.

A mathematical way to say this is "if two notes are an octave apart, the ratio of their frequencies is two to one (2:1)". Although the notes themselves can be any frequency, the 2:1 ratio is the same for all octaves. And all the other intervals that musicians talk about can also be described as being particular ratios of frequencies.

A Harmonic Series Written as Notes



Take the third harmonic, for example. Its frequency is three times the first harmonic (ratio 3:1). Remember, the frequency of the second harmonic is two times that of the first harmonic. So the ratio of the frequencies of the second to the third harmonics is 2:3. From the harmonic series shown above, you can see that the interval between these two notes is a perfect fifth. The ratio of the frequencies of all perfect fifths is 2:3.

Exercise:

Problem:

1. The interval between the fourth and sixth harmonics (frequency ratio 4:6) is also a fifth. Can you explain this?
2. What other harmonics have an interval of a fifth?
3. Which harmonics have an interval of a fourth?
4. What is the frequency ratio for the interval of a fourth?

Solution:

1. The ratio 4:6 reduced to lowest terms is 2:3. (If you are more comfortable with fractions than with ratios, think of all the ratios as fractions instead. 2:3 is just two-thirds, and 4:6 is four-sixths. Four-sixths reduces to two-thirds.)
2. Six and nine (6:9 also reduces to 2:3); eight and twelve; ten and fifteen; and any other combination that can be reduced to 2:3 (12:18, 14:21 and so on).
3. Harmonics three and four; six and eight; nine and twelve; twelve and sixteen; and so on.
4. 3:4

Note: If you have been looking at the harmonic series above closely, you may have noticed that some notes that are written to give the same interval have different frequency ratios. For example, the interval between the seventh and eighth harmonics is a major second, but so are the intervals between 8 and 9, between 9 and 10, and between 10 and 11. But 7:8, 8:9, 9:10, and 10:11, although they are pretty close, are not exactly the same. In fact, modern Western music uses the equal temperament tuning system, which divides the octave into twelve notes that are spaced equally far apart. The positive aspect of equal temperament (and the reason it is used) is that an instrument will be equally in tune in all keys. The negative aspect is that it means that all intervals except for octaves are slightly out of tune with regard to the actual harmonic series. For more about equal temperament, see Tuning Systems. Interestingly, musicians have a tendency to revert to true harmonics when they can (in other words, when it is easy to fine-tune each note). For example, an a capella choral group or a brass ensemble, may find themselves singing or playing perfect fourths and fifths, "contracted" major thirds and "expanded" minor thirds.

Brass Instruments

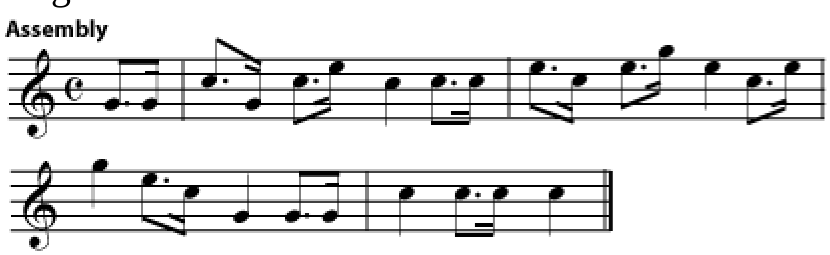
The harmonic series is particularly important for brass instruments. A pianist or xylophone player only gets one note from each key. A string player who wants a different note from a string holds the string tightly in a different place. This basically makes a vibrating string of a new length, with a new fundamental.

But a brass player, without changing the length of the instrument, gets different notes by actually playing the harmonics of the instrument. Woodwinds also do this, although not as much. Most woodwinds can get two different octaves with essentially the same fingering; the lower octave is the fundamental of the column of air inside the instrument at that fingering. The upper octave is the first harmonic.

But it is the brass instruments that excel in getting different notes from the same length of tubing. The sound of a brass instruments starts with vibrations of the player's lips. By vibrating the lips at different speeds, the player can cause a harmonic of the air column to sound instead of the fundamental.

So a bugle player can play any note in the harmonic series of the instrument that falls within the player's range. Compare these well-known bugle calls to the harmonic series above.

Bugle Calls



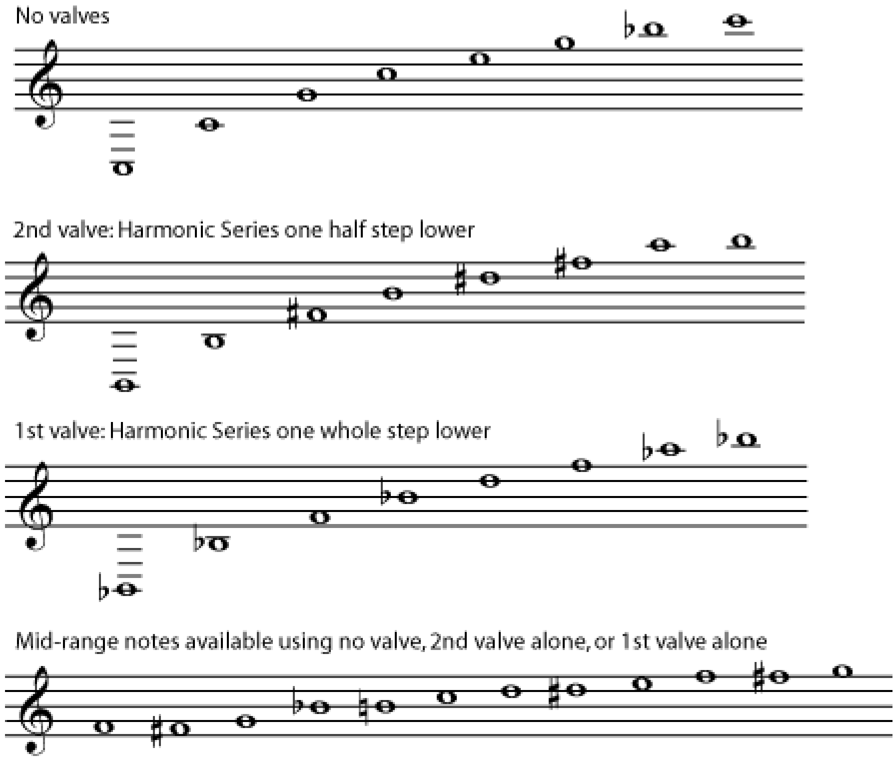
Although limited by the fact that it can only play

one harmonic series, the bugle can still play many well-known tunes.

For centuries, all brass instruments were valveless. A brass instrument could play only the notes of one harmonic series. The upper octaves of the series, where the notes are close together, could be difficult or impossible to play, and some of the harmonics sound quite out of tune to ears that expect equal temperament. The solution to these problems, once brass valves were perfected, was to add a few valves to the instrument. Three is usually enough. Each valve opens an extra length of tube, making the instrument a little longer, and making available a whole new harmonic series. Usually one valve gives the harmonic series one half step lower than the valveless intrument, another one whole step lower, and another one and a half steps lower. The valves can be used at the same time, too, making even more harmonic series. So a valved brass instrument can find, in the comfortable middle of its range (its **middle register**), a valve combination that will give a reasonably in-tune version for every note of the chromatic scale. (For more on the history of valved brass, see History of the French Horn. For more on how and why harmonics are produced in wind instruments, please see Standing Waves and Wind Instruments)

Note: Trombones use a slide instead of valves to make their instrument longer. But the basic principle is still the same. At each slide "position", the instrument gets a new harmonic series. The notes in between the positions aren't part of the chromatic scale, so they are usually only used for special effects like **glissandos** (sliding notes).

Overlapping Harmonic Series in Brass Instruments



These harmonic series are for a brass instrument that has a "C" fundamental when no valves are being used - for example, a C trumpet. Remember, there is an entire harmonic series for every fundamental, and any note can be a fundamental. You just have to find the brass tube with the right length. So a trumpet or tuba can get one harmonic series using no valves, another one a half step lower using one valve, another one a whole step lower using another valve, and so on. By the time all the combinations of valves are used, there is some way to get an in-tune version of every note they need.

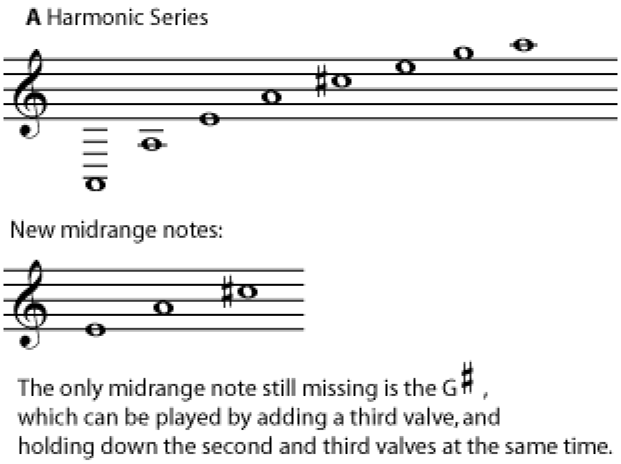
Exercise:

Problem:

Write the harmonic series for the instrument above when both the first and second valves are open. (You can use this PDF file if you need staff paper.) What new notes are added in the instrument's middle range? Are any notes still missing?

Solution:

Opening both first and second valves gives the harmonic series one-and-a-half steps lower than "no valves".



Note: The French horn has a reputation for being a "difficult" instrument to play. This is also because of the harmonic series. Most brass instruments play in the first few octaves of the harmonic series, where the notes are farther apart and it takes a pretty big difference in the mouth and lips (the embouchure, pronounced AHM-buh-sher) to get a different note. The range of the French horn is higher in the harmonic series, where the notes are closer together. So very small differences in the mouth and lips can mean the wrong harmonic comes out.

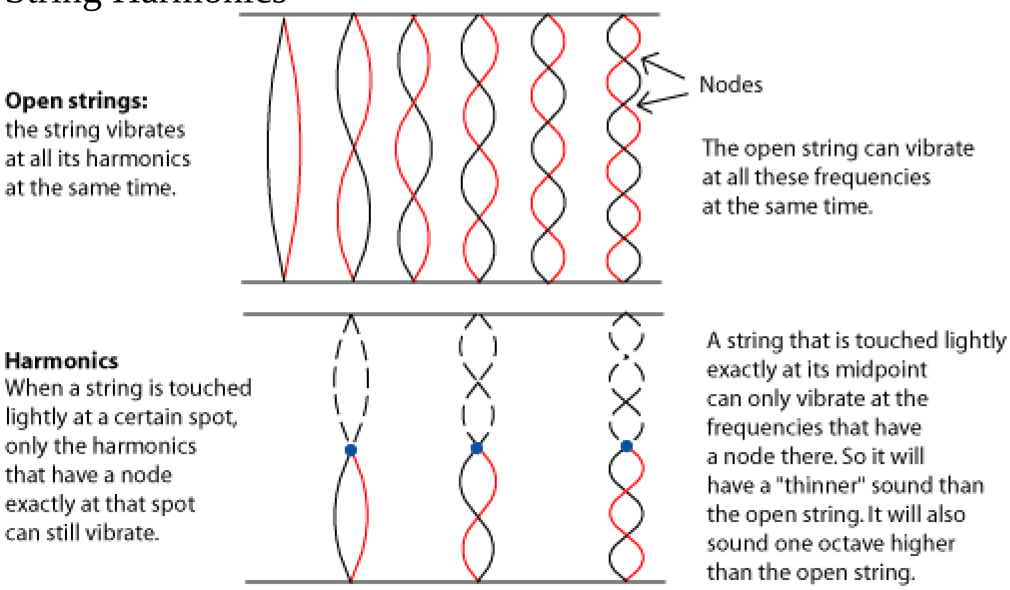
Playing Harmonics on Strings

String players also use harmonics, although not as much as brass players. Harmonics on strings have a very different [timbre] from ordinary string sounds. They give a quieter, thinner, more bell-like tone, and are usually used as a kind of ear-catching-special-effect.

Normally when a string player puts a finger on a string, he holds it down tight. This basically forms a (temporarily) shorter vibrating string, which then produces an entire harmonic series, with a shorter (higher) fundamental.

In order to play a harmonic, he touches the string very, very lightly instead. So the length of the string does not change. Instead, the light touch interferes with all of the vibrations that don't have a node at that spot. (A **node** is a place in the wave where the string does not move back-and-forth. For example, the ends of the string are both nodes, since they are held in place.)

String Harmonics



The thinner, quieter sound of "playing harmonics" is caused by the fact that much of the harmonic series is missing from the sound, which will of course be heard in the [timbre]. Lightly touching the string in most spots will result in no sound at all. It only works at the precise spots that will leave some of the main harmonics (the longer, louder, lower-numbered ones) free to vibrate.

Orchestral Instruments
An introduction to the instruments of the modern Western orchestra.

Introduction

The modern Western orchestra first developed in Europe over a period of several centuries, but in modern times it has become widely adopted all over the world. Various types of bands and smaller ensembles composed mainly of orchestral instruments are also very popular. So many people are familiar with the "orchestra section" method of classifying musical instruments. Here are the sections of the orchestra and the instruments commonly found in them.

The Sections of the Orchestra

The typical orchestra is divided into four groups of instruments: strings, woodwinds, brass, and percussion. The typical Western marching band, school band, or wind ensemble (woodwinds and brass together are **winds**) leaves out the strings, but otherwise uses most of the same instruments as the orchestra.

Strings

There are four stringed instruments commonly used in the modern orchestra: the violin, viola, cello, and bass. All are made of wood and have four strings. All are usually played by drawing a bow across the strings, but are also sometimes played by plucking the strings.

The violin is smallest, has the highest sound, and is most numerous; there are normally two violin sections (the first violins and second violins), but only one section of each of the other strings.

The **viola** is only a little bit bigger than a violin, with a slightly deeper and mellower tone. A nonmusician can have trouble telling a viola from a violin without a side-by-side comparison.

The **cello** is technically the "violoncello", but few people call it that anymore. There is no mistaking it for a violin or viola; it is much bigger, with a much lower, deeper sound. Whereas violins and violas are held up under the chin to be played, cellos and basses have to rest on the floor to be played.

The **bass**, also called the "double bass" (its official name), "standing bass" or "string bass", is so big that the player must sit on a high stool or stand up to play it. It has a very low sound.

Woodwinds

The woodwind members of the orchestra are the flute, oboe, clarinet, and bassoon. There can be two, three, or four, of any of these woodwinds in an orchestra, depending on the size of the orchestra and the piece being played. All of the modern orchestral woodwinds are played by blowing into them and **fingering** different notes using keys that cover various holes. Most, but not all, are made of wood and have at least one piece of reed in the mouthpiece.

> **Note:** You may be surprised that the saxophone is not here. This is the one instrument that is always found in bands and wind ensembles, but only very rarely plays in the orchestra.

Although flutes may be made of wood, the orchestral flute is usually made of metal. It also does not have a reed. It is grouped with the woodwinds partly because it is in fact more closely related to those instruments than to the brass (please see Wind Instruments: Some Basics), but also because the color of its sound fits in the woodwind section. The sound is produced when the player blows across a hole in the side (not the end) of the instrument. It has a clear, high sound that can be either gentle or piercing.

An even higher-sounding instrument is the **piccolo**, a very small flute that is much more common in bands than in orchestras.

The oboe is the instrument that traditionally sounds the first "A" that the orchestra tunes to. It is black, made of wood, and at sight can be mistaken by the nonmusician for a clarinet. But its sound is produced when the player blows in between two small reeds, and its high "double-reed" sound is not easily mistaken for any other instrument. The **cor anglais**, or **English horn**, is a slightly larger double reed instrument with a deeper, gentler tone, that is sometimes called for in orchestral music.

The clarinet is also black and normally made of wood, although good plastic clarinets are also made. It uses only a single reed. It is a versatile instrument, with a very wide range of notes from low to high, and also a wide range of different sound colors available to it. In the orchestra, clarinets are no more numerous than the other woodwinds, but it is usually the most numerous instrument in bands and wind ensembles because of its useful versatility. There are many sizes of clarinet available, including bass and contrabass clarinets, but the most common is the B flat clarinet. The clarinet is the only common orchestral woodwind that is usually a transposing instrument, although there are less common woodwinds, such as English horn, that are also transposing instruments.

The bassoon is the largest and lowest-sounding standard orchestral woodwind. (Bass clarinet and contrabassoon are used only occasionally.) It is a long hollow tube of wood; you can often see the tops of the bassoons over the rest of the orchestra. Like the oboe, the bassoon is a **double reed** - the player blows between two reeds - but the player does not blow into the end of the bassoon. The air from the reeds goes through a thin metal tube into the middle of the instrument.

Brass

The orchestral brass are all made of metal, although the metal can be a silvery alloy instead of brass. The sound is actually produced by "buzzing" the lips against the mouthpiece; the rest of the instrument just amplifies and

refines the sound from the lips so that it is a pretty, musical sound by the time it comes out of the **bell** at the other end of the instrument. A slide, or three or four valves, help the instruments get different notes, but players rely heavily on the harmonic series of their instruments to get the full range of notes. (Please see Wind Instruments: Some Basics for more on the subject.) The orchestral brass instruments are the trumpet, French horn, trombone, and tuba. As with the woodwinds, the number of each of these instruments varies depending on the size of the orchestra and the piece being played. There are usually two to five each of trumpets, horns, and trombones, and one or two tubas.

The trumpet is the smallest, highest-sounding orchestral brass instrument. Its shape is quite cylindrical (it doesn't flare much until the very end), giving it a very clear, direct sound. Trumpets may read in C or may be B flat transposing instruments. The **cornet**, which is more common in bands than in orchestras, is very similar to the trumpet and the two instruments are often considered interchangeable. The cornet has a more conical, gently-flaring shape and a slightly mellower sound.

The French horn, or **horn**, is much more conical than the trumpet and has a much mellower, more distant sound. It has a wide range that overlaps both the trumpet and trombone ranges, and in the orchestra is often used to fill in the middle of the brass sound. Its long length of tubing is wrapped into a circular shape and the bell faces backward and is normally rested on the player's leg. It is a transposing instrument that usually reads music in F.

The trombone is the only valveless brass instrument in the modern orchestra. One section of its tubing - the **slide** - slides in and out to specific **positions** to get higher and lower pitches, but, as with the other brass, it uses the harmonic series to get all the notes in its range. Its range is quite a bit lower than the trumpet, but it also has a brassy, direct (cylindrical-shape) sound.

There are a few instruments in the middle and low range of the brass section that are commonly found in bands, but very rare in the orchestra. The baritone and euphonium play in the same range as the trombone, but have the more cylindrical shape and a very mellow, sweet sound. In marching bands, the horn players often play mellophone and the tuba

players play the sousaphone. The **mellophone** is an E flat or F transposing instrument with a forward-facing bell that is more suitable for marching bands than the French horn. The **sousaphone** was also invented for use in a marching band; its tubing is wrapped so that the player can carry it on the shoulders.

The tuba is the largest, lowest-sounding orchestral brass instrument. It is a conical brass instrument, with a much mellower, distant sound than the trombone. Its bell (and the bell of the baritone and euphonium) may either point straight up or upward and forward.

Percussion

In a Western orchestra or band, anything that is not classified as strings, woodwinds, or brass goes in the percussion section, including whistles. Most of the instruments in this section, though, are various drums and other instruments that are hit with drumsticks or beaters. Here are some of the more common instruments found in an orchestra percussion section.

Timpani are large kettledrums (drums with a rounded bottom) that can be tuned to play specific pitches. An orchestra or wind ensemble will usually have a few tympani of various sizes.

Other common drums do not have a particular pitch. They are usually cylindrical, sometimes with a drum head on each end of the cylinder. They include the small **side drum**, which often has a **snare** that can be engaged to give the drum an extra rattling sound, the medium-sized **tenor drum**, and the large **bass drum**. All orchestral drums (including tympani) are played using hard drum sticks or softer beaters. Drums that are played with the hands, like bongos, are rare in traditional orchestras and bands.

Cymbals can be clashed together, hit with a beater, or slapped together in "hi-hat" fashion. For smaller ensembles, various cymbals and drums may be grouped into a **drum set** so that one player can play all of them. **Gongs** are usually larger and thicker than cymbals and are usually hit with a soft beater.

There is only one group of common percussion instruments on which it is easy to play a melody. In these instruments, bars, blocks or tubes are arranged in two rows like the black and white keys of a piano keyboard. Orchestral **xylophones** and **marimbas** use wooden bars arranged over hollow tubes that help amplify their sound. The **glockenspiel** uses metal bars (like the familiar children's xylophone), and **tubular bells** use long, hollow, metal tubes.

Common percussion extras that add special color and effects to the music include the tambourine, triangle, maracas and other shakers, castanets, claves and various wood blocks, and various bells and scrapers.

Wind Instruments: Some Basics
For middle school and up, some terms that are useful to know when discussing aerophones (wind instruments).

Introduction

The brass and woodwind sections of the orchestra - all the instruments that one blows into to produce a sound - are called the **wind instruments**, or **winds**. The technical term for these instruments is aerophones. There are several basic terms that you need to know in order to discuss wind instruments and the playing of wind instruments. Some of the most common are introduced here.

Mouthpieces: Getting the Sound Started

In most wind instruments, the air is blown into the instrument at or near one end of the tube and exits at the other end. The place where the air is blown in is the **mouthpiece**. It is often detachable from the instrument, allowing the player to use the same mouthpiece on different instruments, or different mouthpieces on the same instrument, as needed. The sound vibration usually begins at the mouthpiece, and wind instruments are classified by mouthpiece types.

Reed instruments use small, rectangular pieces of reed plants (the pieces are called simply **reeds**) in their mouthpieces. The reed vibrates very quickly, opening and closing the end of the instrument like an incredibly fast valve. When the rapid puffs of air coming through this "valve" cause a sympathetic vibration of the air in the body of the instrument, the result is a woodwind sound. When they don't, the result is a squeak familiar to all reed players. In a **single-reed** instrument, the reed vibrates against the mouthpiece. In a **double-reed** instrument, two pieces of reed vibrate against each other.

In flute-type instruments, a narrow airstream vibrates quickly over and under a sharp edge. (Please see Flutes for more about how this type of mouthpiece works.)

In brass instruments, the players lips vibrate against each other and against the rim of a **cup mouthpiece**. Note that an instrument is classified as brass not because it is made of metal, but because it has this type of mouthpiece, which relies on vibrating lips.

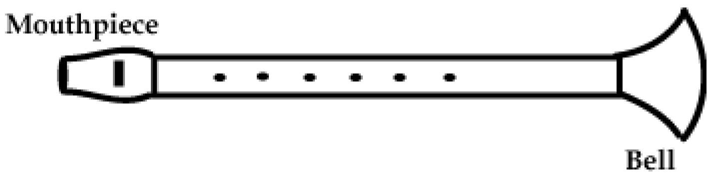
In all of these cases, the mouthpiece vibration is the original vibration that the rest of the instrument picks up, magnifies, and turns into a pretty sound.

Bells and Bores: The Shape of the Instrument

Most wind instruments are vaguely tube-shaped, because a long, thin column of air is a good place to set up a standing waves of air. The properties of this standing sound wave inside the instrument are what give the sound its pitch, its dynamic level (loudness or softness), its harmonics, and its timbre (color). So an instrument's sound depends mostly on the size and shape of the tube that the air moves through.

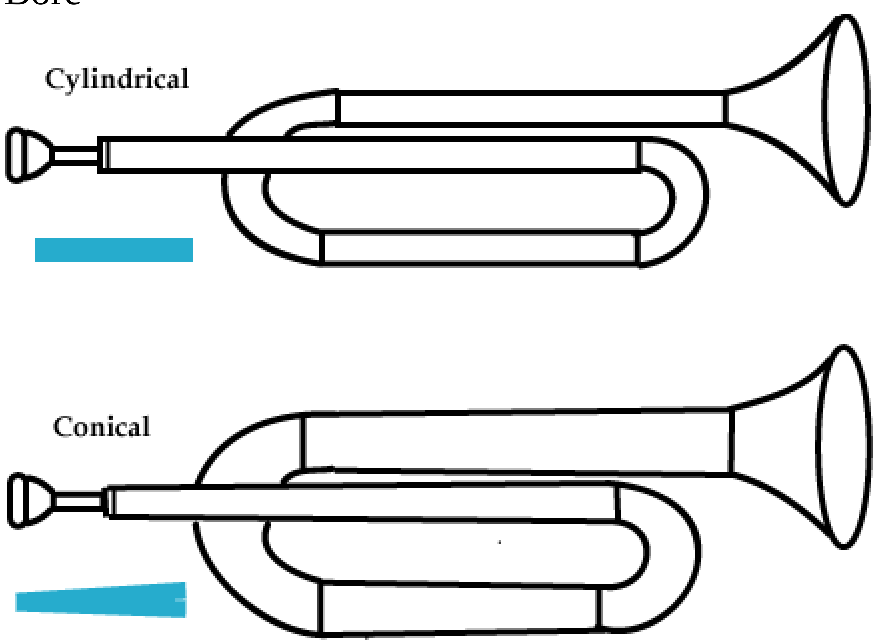
Note: Interestingly, whether the tube is straight or bent into circles or ovals doesn't seem to affect the sound much, although a very sharp bend in the instrument does affect the sound a little. Whether an instrument is straight or bent into circles usually depends on what's easiest for the musician to hold and the instrument-maker to shape.

The air enters the instrument at the mouthpiece (see above). After a length of tube which widens gradually or hardly at all, the other end of the instrument often flares abruptly. This flared section at the end of the instrument is the **bell**. The bell can be quite large and gradual, as in a French horn, or small and abrupt, as in a trumpet, or even narrowing, as in a bassoon.
Basic Wind Instrument



In between the mouthpiece and the bell, the space inside the instrument that the air moves through is the **bore** of the instrument. The bore of an instrument is often described as being either cylindrical or conical. A **cylindrical bore** stays about the same width from the mouthpiece to the bell. A **conical bore** gets gradually wider as it moves from the mouthpice to the bell. The bore of the instrument strongly affects its timbre. For more complete information on how the shape of a wind instrument affects its sound, please see Standing Waves and Wind Instruments.

Bore



Bore affects the timbre of the instrument. In general, instruments with a cylindrical bore have a more direct sound with less complex harmonics. Instruments with a conical bore usually have a mellower sound with more complex harmonics.

Lips, Tongue, and Fingers: Playing the Instrument

Most wind instruments require the player to do something very specific with the lips and the facial muscles while blowing, in order to get a good, controlled sound. (Brass instruments will get no sound at all unless the lips are buzzing against each other and the mouthpiece.) The formal term for what a player does with the lips and face is **embouchure**; the informal term is **chops**.

Unless they are slurred, notes played on wind instruments are **tongued**. This means that the tongue, which has temporarily blocked or interrupted the airstream, begins each note by releasing the airstream again. Tonguing is usually done with the tip of the tongue, as if the player is saying "tah". But sometimes, when the music is very fast, some wind players will **double tongue** (tah-kah-tah-kah) or **triple tongue** (tah-kah-tah tah-kah-tah) the notes, using the back as well as the front of the tongue. Flutes can also get an effect called **flutter tongue** by using an articulation that resembles the rolled Spanish "rr".

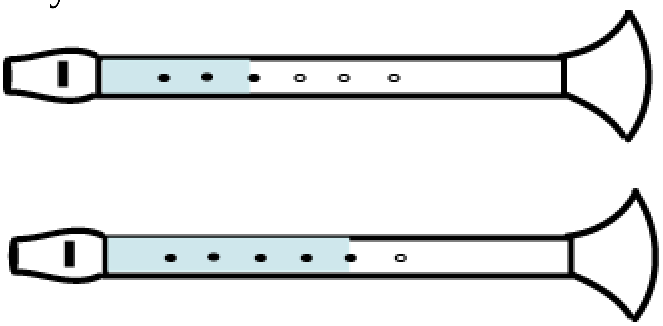
In the meantime, the fingers are usually involved in making the column of air in the instrument shorter or longer, to make the pitch higher or lower. This may involve a sliding section of the instrument (as in a trombone), or **fingerholes** that can be covered or uncovered with the fingers (as in recorders).

In most modern instruments, however, it usually involves either keys or valves. The **fingering** of a note is the keys or valves that need to be held down for that note. But most instruments can get more than one note with the same fingering, by changing the embouchure to get different harmonics of the standing wave. In fact, brass winds can get so many different harmonics with one fingering that changing the embouchure is the main way to play the instrument. Brass usually use valves, and woodwinds usually use keys. Keys and valves work in fundamentally different ways.

That vibrating standing-wave column of air inside the instrument generally ends at the first place where air can escape from the instrument. So (this is simplified for explanation purposes), the more fingers a recorder player is holding down, the longer the column of air and the lower the pitch. But it

can be difficult (on some large instruments, impossible) to completely cover all the holes with the fingers, so most modern woodwind instruments use **keys** instead. The fingers press down the keys, and the keys cover the holes as needed, usually with a pad that covers the hole more completely than a finger could, and sometimes also using a lever that lets the finger press in one easy-to-reach spot, while the lever presses the pad over a hole in a more-difficult-to-reach spot.

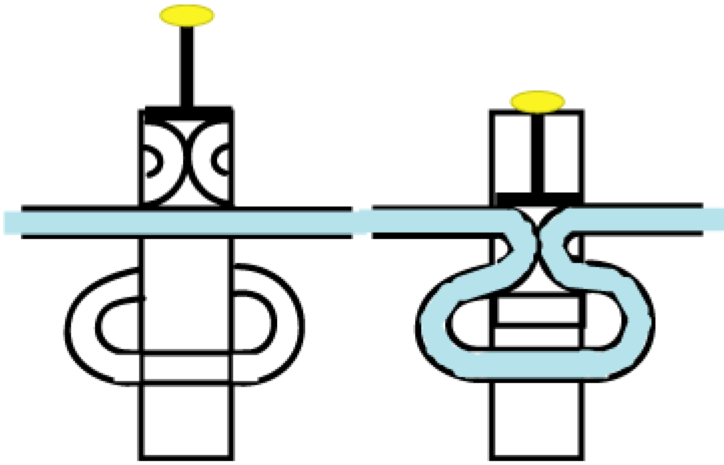
Keys



In general, the more holes that are closed with a key or covered by a finger, the longer the standing wave inside the instrument, and the lower the pitch.

Valves are more commonly found on brass instruments. Pressing a **valve** makes the air flow through an extra section of tube, temporarily making the instrument longer in between the mouthpiece and the bell. The slightly longer instrument gets a slightly lower fundamental harmonic, and a lower harmonic series. (A few valves are **ascending valves**, which cut off a section of tubing and so raise the pitch.) Press the button in this animation to see how the air gets redirected through one type of (**descending**) valve.

Valves



The figure and the animation show one type of piston valve. Other styles of valves, including rotary valves as well as other types of piston valves, have different arrangements for the air flow inside the valve, but the purpose is always to redirect the air when the valve is pressed, opening up or cutting off a section of tubing.

Most brass instruments can play an entire chromatic scale with just a few valves. They use small changes in the embouchure to get many different notes from the harmonic series for each valve. But woodwinds have many more keys and fingerings available. Typically a woodwind can play the notes in an entire octave just by changing fingerings. Then a large change in the airstream and embouchure is needed to switch to the next harmonic, so that the next octave can be played. This big change is called **overblowing**.

Some brass instruments may also have a **spit valve**, a small hole that is normally closed but that the player can open quickly with a small key. This is not used while playing the instrument. It is used to empty the instrument of what players call "spit". Water vapor from the warm, moist breath of the player condenses in the instrument, especially when it is cold. (And, yes, there's probably a little actual spit in it, too, but not much). This can cause a bubbling sound in the tone. The spit valve is placed at a spot where the water naturally accumulates (due to gravity), giving the player a way to quickly empty the instrument during rests.

Wood and Brass: Instrument Materials

Calling the two main wind sections of the orchestra woodwinds and brass is a bit misleading. The important difference between the two groups is how the sound is first produced, not what the instrument is made of. (In a "brass" instrument, the lips are buzzed against the rim of the mouthpiece. In a "woodwind", the sound begins either with one or two vibrating reeds, or at a sharp edge in the mouthpiece.)

"Brass" instruments are usually made of brass, an alloy of copper and zinc. They may be the normal color of brass metal, or they may be tinted to a different metallic color. For example, nickel may be added to the alloy to give the instrument a silver color. Occasionally brass instruments are not made of metal at all; for example, the sousaphone, a tuba used in marching bands, is often made of (lighter-weight) fiberglass.

"Woodwinds" are often made of hardwood, but saxophones are normally made of brass, and most orchestral flutes are made of "nickel-silver" brass. There are also good-quality plastic woodwinds that may be preferable to the wooden versions in some situations - for example, playing in rain, heat, or cold.

Other materials are often needed to make an instrument work well. Felt pads, pieces of cork, metal keys, and various oils help to keep the valve and key action quiet while keeping the instrument from leaking air in the wrong places.

The French Horn
An introduction to and short history of the orchestral brass instrument called the "French horn" or "horn",

Introduction

The middle-range brass instrument in the Western orchestra or band is sometimes called the **horn**, sometimes the **French horn**. It is an aerophone with a conical bore, a fairly small mouthpiece, a widely flaring bell, and about 17 feet of metal tubing wrapped into a circular shape to make it easier to hold. It is a transposing instrument; most horn music is written in F.

The Instrument

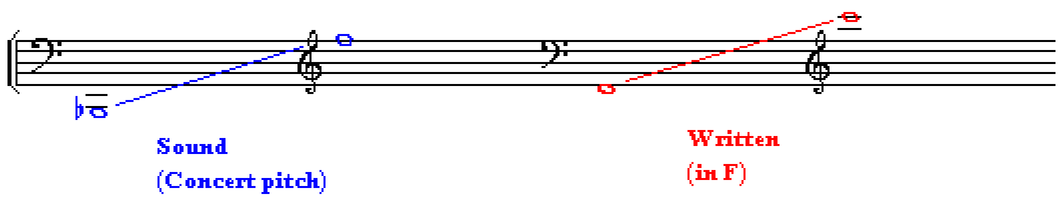
The French horn

As in other brass instruments, the sound of a horn is produced by "buzzing" the lips against the mouthpiece. Players get higher or lower notes by changing the embouchure (the lips and facial muscles), but the three valves that open extra sections of tubing are also needed to get all the notes possible on the horn (see below). The left hand works the valves; the right hand is normally placed inside the bell of the instrument, where it can be used to help tune the instrument and make changes in its timbre.

The most common modern instrument is a "double horn", which has two parallel sets of tubing. One set makes it an F horn; the other a smaller, higher B flat horn. (See History, below for an explanation of how and why

instruments come in different keys.) A fourth valve called the **trigger** is used to switch between the two sides of the instrument. But as a transposing instrument, the double horn is considered to be "in F"; music for the instrument is usually written in F, allowing individual players to choose whether to use the F or the B flat "side" of the instrument for any given note.

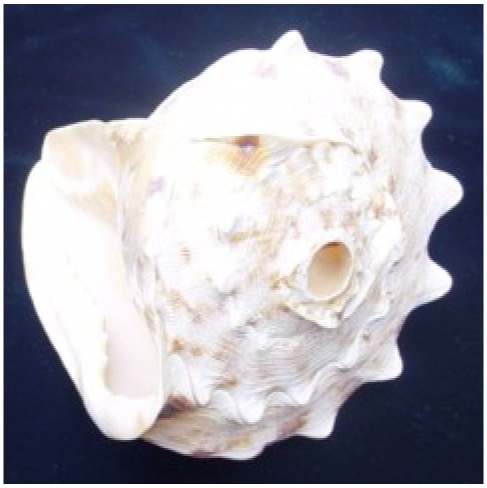
The Range of the Horn



The modern horn is a transposing instrument; music for horn is in F, written a perfect fifth higher than it sounds.

The **mellophone** is a brass instrument closely related to the French horn. It is only half the length of a normal horn, which has two useful effects. One is that it is lighter to carry around. The other is that, while playing in the same range as the French horn, it is playing lower in the harmonic series, where the harmonics are not so close together and it is not so easy to play the wrong harmonic. (See below.) Because of these advantages, the bell-front mellophone (which looks a bit like a rounded oversized trumpet) is commonly used by French horn players in marching bands.

History



Horns and other brass instruments are played by buzzing the lips against the mouthpiece. The very earliest instruments in this family were natural objects (such as animal horns or this conch shell) that could be played by buzzing the lips against a hole in one end of the object.

The very earliest horns were hollowed-out animal horns, or other natural objects that would resonate at a particular pitch when the player buzzed the lips against a hole in one end.

The modern instrument is descended from earlier brass instruments that were used for centuries in Europe for military and hunting purposes. These horns came in various different sizes and shapes. The orchestral horn is particularly descended from the French **trompe de chasse**; hence the name "French horn". This hunting horn, in use in France in the seventeenth century, was a slender tube that was coiled into a large hoop that could

easily be slung over a huntsman's shoulder. The tube was only about 7 feet long and was much more cylindrical than a modern horn. The eighteenth-century **cor de chasse**, the typical instrument in the orchestra of Bach's and Handel's time, was twice as long and coiled into a double hoop. This instrument had no valves and was originally played with the bell pointing up and out. It could therefore play only the notes of a single harmonic series. This severely limited the parts a single instrument could play; a horn that could play a harmonic series on an E flat fundamental, for example, could play some, but not all, of the notes in the key of E flat, could play even fewer notes in keys closely related to E flat, and could play no notes at all in keys not related to E flat.

This meant that a horn player who wanted to be able to play in more than one key would need several different horns, would need time to switch from one horn to another whenever the music changed keys, and would still not be able to play every note in the key. For centuries, the history of the horn was a history of the search for solutions to these limitations.

One solution to this problem was to add a second set of players. One pair of horns could play in one key; the other in the other key. The setup of the modern orchestra often still reflects this early solution, with four horns playing in two pairs, and the third horn part almost acting like another first horn.

A second solution was to change the position of the horn so that the bell rested on the player's leg, and the right hand could be placed inside the bell. The player could then use the hand in two different ways, partially blocking the air flow, or almost completely **stopping** the air with the hand. Partially blocking the air lowered the pitch by about a half step, but the full stop basically shortened the playing length of the instrument and thus raised the pitch by about a whole step. The timbre of half-stopped and stopped notes are very different from each other and also very different from the sound of "open" notes. They can sound very jarring to modern ears. But **hand-horn technique**, invented by a Dresden horn player named Hampl around 1770, allowed the entire chromatic scale to be played on a single instrument without pause. This was so useful that hand-horn became widely accepted

in spite of its timbre idiosyncrasies. In fact, it continued to be expected and used for decades after it was no longer really necessary.

Finally, there were many mechanical solutions. A very popular early solution involved adding extra lengths of tubing to the instrument to change its key. There were different ways to add the extra tubing: **crooks** could be fitted into sockets in the hoop, **couplers** could be added in between the mouthpiece and the instrument. Now a single horn player could play in many different keys with only one horn and a bag of crooks or couplers. He still needed time to change the crooks on his instrument when the music changed keys, but not as much time as before. To simplify things for the horn player, the composer would indicate which crook was needed (a movement might be labelled "for horn in A") and transpose the part for that instrument. This made the music easy to read - the first harmonic always looked like a C, the third like a G, and so on - easy for the horn player of that time, whose instrument was transposing the notes for him, but harder for a modern horn player trying to read older music, who may have to transpose the A part to her accustomed horn in F.

Of course, the ideal horn could switch crooks nearly instantaneously, and many new horns were invented to provide this solution. Some more successful than others. The **omnitonic horn** attached all crooks to the instrument, with a device to switch from one tube to another. This made it very easy and fast to change crooks, but hand horn technique was still needed to be able to play any note in the key.

The invention that really freed the horn to play the full chromatic scale easily was the valve. A valve can open and close almost instantly, redirecting the air through an extra crook in the middle of the instrument. It's really not clear who first invented a valved horn and when, but n 1818 a valve horn with two piston valves was patented; in the 1830's a third piston was added. Although most other modern brass still use piston valves, the horn switched to rotary valves, apparently invented by Joseph Riedl of Vienna around 1832. The modern horn uses three rotary valves, which lower its natural (F) harmonic series by a half step, a whole step, and one and a half steps, giving the horn a quick and easy chromatic scale. (For

more on why three valves is enough for a brass instrument, see The Harmonic Series.)

Most modern horns are also **double horns**, that is, two horns in one. When instrument makers and players were settling on which of the many instruments (Horn in D? In E flat?) to use for the modern valved horn, the F horn was originally chosen as having a particularly full, moderate, and pleasing sound. But it is difficult to play high notes accurately on the F horn, so a second set of crooks, for the smaller, higher B flat horn, was added. A fourth valve, or **trigger** opens the shorter set of crooks, switching the instrument from the F "side" to the B flat "side" to play high notes.

Repertoire

Horns are part of the standard orchestra. A small orchestra will have two horns, a large one four or more. The first horn (principal) part may be so tiring that a large orchestra may have an associate principal horn player to take the principal's place on some of the program, and/or an assistant principal horn player to play along with the principal on non-solo sections. A typical band or wind ensemble will also have at least four horns. Some easy-to-find recordings that feature horns in larger ensembles are Strauss' "Blue Danube" waltz, the "Waltz of the Flowers" from Tchaikovsky's ballet *The Nutcracker*, the "Nocturne" from Mendelssohn's *Midsummer Night's Dream*, and the "Ride of the Valkyries" music from Wagner's opera *Die Walkuere*.

Horns are also well-represented in the chamber music repertoire. The standard brass quintet includes a horn, and so does the standard woodwind quintet. There is also much music written for horn quartet, some - but by no means all - of it derived from orchestral works.

In spite of the historic limitations of the instrument (see history, above), several famous composers also wrote solo music for the horn. The most well-known of these are the four Mozart horn concertos.

Practical Information for Composers and Arrangers

The French horn is a versatile brass instrument with a large range, very useful in many different kinds of arrangements. Played with a brassy tone, or grouped with other brass, it can give a military or fanfare flavor, but, played with a mellower tone it also blends very well with orchestral woodwinds. It can give a sweet, haunting color to solos and easily evokes hunting or other pastoral scenes.

The most important thing to remember when writing for horn is that it is a transposing instrument; most players are only comfortable reading parts that have been transposed into F. If you do not know how to transpose, see the modules on Transposing Instruments and Transposition.

The horn is a more agile instrument than the lower brass, but not as agile as the trumpet. Avoid writing too many fast notes or large leaps in a row. Note also that the horn plays higher in its harmonic series than other orchestral brass instruments. This means the notes at the top of the intrument's range (the notes above the treble staff in the instrument's written range) that have the same fingering are so close together that it is very easy to hit the wrong note. Use this range sparingly unless writing for professionals. Even in the middle register, an inexperienced player aiming for one note can very easily hit a different note that has the same fingering and only slightly different embouchure. This is what gives the horn its reputation as an instrument that is "difficult to play".

Suggested Resources

To hear typical music featuring the French horn, search for "Mozart horn concerto" or "Strauss horn concerto".

Transposing Instruments
Music for transposing instruments is not written or read at concert pitch.

What is a Transposing Instrument?

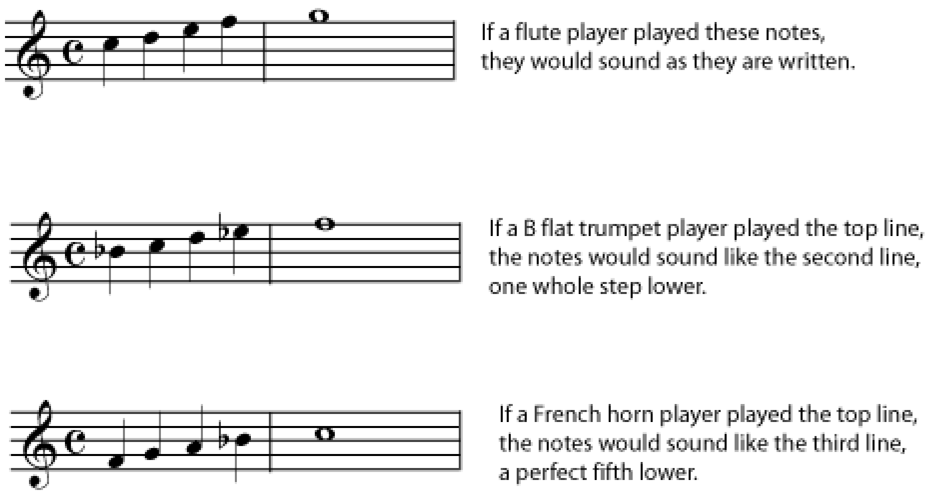
It is easier for musicians to play together, talk to each other about music, and share written music with each other, if everyone agrees on the same names for each pitch. The most widely used standard is called **concert pitch**. Used in most genres of Western music, concert pitch is usually defined by saying that a pitch that sounds at **440 hertz is an "A"**, with all other pitches related to that A using equal temperament tuning.

Even though concert pitch is defined by the sound of an "A", instruments that read music at concert pitch are called **C instruments**. This is because the key of C is the "natural" key, the major key that has no sharps or flats, only natural notes. (You may wonder why A is not the natural key. As is true for so many aspects of music notation and theory, there is no logical reason; it is just a happenstance that arose out of the history of Western music.)

Many instruments are C instruments. For example, piano, organ, oboe, violin, guitar, and trombone are all C instruments. A pianist who sees a written C will play a note that the violinist would agree is a C. This may seem obvious, but a clarinet player who sees a C on the page will play a note that does not sound like a C to the other players. This is because the clarinet is a **transposing instrument**. **The music for transposing instruments is not written or read at concert pitch.** The clarinet player, for example, seeing a C on the page, will play a note that sounds like a B flat. The clarinet is therefore called a B flat instrument. A French horn player, seeing a C on his "horn in F" or "F horn" part, will play a note that sounds like an F. So the name of the instrument ("B flat clarinet" or "F horn") tells you which concert-pitch note the instrument plays when given a written C.

Transposing does not just change the written C, however; it changes every note. For example, a B flat instrument plays every note a whole step lower than written, not just the C. This means that if you want the clarinet player

to play particular concert-pitch notes, you must write those notes one whole step higher than you would for a non-transposing instrument.



Since every note of the scale is changed, the result is a different scale. This means that the part for the transposing instrument will be in a different key and have a different key signature than the parts for C instruments. Changing music to put it into a different key is called transposing the music. Music for transposing instruments must be properly transposed in order for most players to be able to read it. (There are musicians who can "transpose at sight," for example horn players who can read concert-pitch music and play it at concert pitch, but this is unusual.)

Transposing and Non-transposing Instruments

A complete list of all the transposing instruments would be very long. Many are very rare. I will list here only the most common ones. Then I'll discuss a couple of issues that sometimes cause confusion: octave-transposing C instruments and non-C, non-transposing instruments.

Common Transposing Instruments

- **Clarinet** is usually a Bb instrument. The most common clarinet sounds one whole step lower than written, so parts for it must be written one

whole step higher than concert pitch. Like French horns, clarinets used to come in several different keys, and clarinets in A (with parts that are written a minor third higher) and other keys can still be found.

- **Alto and Baritone Saxophone** are Eb instruments. Parts for alto saxophone are transposed up a major sixth. Parts for bari sax are transposed up an octave plus a major sixth.
- **Tenor and Soprano Saxophone** are Bb instruments. Parts for soprano sax are written a step higher than they sound, and parts for tenor sax are transposed up an octave plus a whole step (a major ninth).
- **English Horn** is an F instrument. Parts for English horn are transposed up a perfect fifth.
- **Trumpet and Cornet** can be in B flat or C, depending on the individual instrument. B flat is the more common key for cornet. If you are writing for a particular player, you may want to find out if a C or B flat part is expected.
- **French horn** parts are usually written in F these days, up a perfect fifth. However, because of the instrument's history, older orchestral parts may be in any conceivable transposition, and may even change transpositions in the middle of a piece. Because of this, some horn players learn to transpose at sight.
- **Alto flute** is in G, written a fourth higher than it sounds.
- Tubas and euphoniums may also be transposing instruments. Some tuba and euphonium parts are written as bass clef C parts (sometimes even when the instrument played is nominally not a "C instrument"; see below for more about this). But in British-style brass bands, BBb and Eb tubas (called basses) are written in treble clef. The BBb is written two octaves and a major second higher than it sounds, and the Eb an octave and a major sixth higher than it sounds. in France (and in the case of parts printed in France), you find Bb euphoniums (calles basses or petites basses) written for in bass clef transposing by a major second, and bass tubas (called contrebasses) in Bb written for in bass clef transposing by a major ninth. If you are writing for a particular group or player, you may want to check to see what kind of instrument is available and what transposition the player is comfortable with.

Some transposing instruments do not change key, but play an octave higher or lower than written.

- **Guitar** parts are written one octave higher than they sound.
- **Men's voices**, when given a melody written in treble clef, will usually sing it one octave lower than written.
- **String Bass** parts are written one octave higher than they sound.
- **Piccolo** parts are written one octave lower than they sound.
- **Contrabassoon** parts are written one octave higher than they sound.
- **Handbell** and **handchime** parts are written one octave lower than they sound.

There are also instruments that **do not transpose** but are also **not considered C or concert-pitch instruments**. Players of these instruments read concert-pitch music, but the instruments are considered to be fundamentally pitched on a note other than C. This is of very little practical importance, but is an issue that confuses some people, so let's take two examples. Soprano and tenor recorders, when all the finger-holes are covered (so that the air must go through the entire instrument), play a C. Alto recorders, when all the finger-holes are covered, play an F. Like B flat trumpets, this would seem to make alto recorder a good candidate to be a transposing instrument. If it were, a player could easily switch from one size recorder to another; a written C would have the same fingering on all instruments. But recorder history and tradition differ from trumpet history and tradition; so, although alto recorder can be considered to be "pitched in F", alto players learn to read at concert pitch, associating the fingerings with different notes than a soprano or tenor player would.

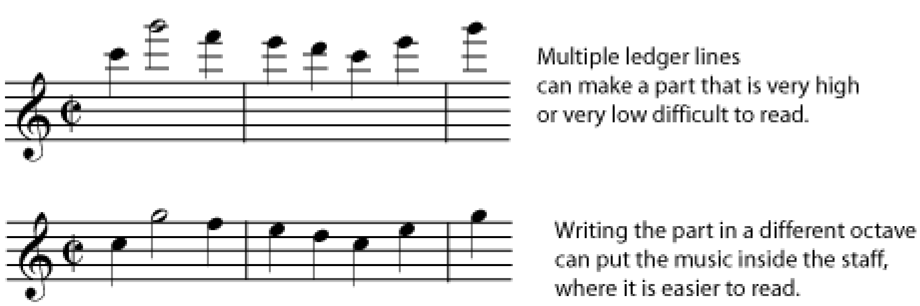
The second example is from brass instruments. The fundamental pitch of a woodwind (the recorder, for example) is considered to be the lowest note it can play when all holes are closed. The fundamental pitch of a brass instrument, on the other hand, is considered to be the fundamental of the harmonic series it plays when no valves are being used. For example, the C trumpet, using no valves, plays a harmonic series based on C, while a B flat (transposing) trumpet plays a B flat harmonic series. Tubas, on the other hand, can be based on several different harmonic series, including C, B flat, F, and E flat. But these are not necessarily transposing instruments. A tuba player playing a B flat instrument may read a transposing B flat part, or may read concert-pitch music and simply use different fingerings for the same note than a player on a C instrument.

Some Non-transposing, Non-C Instruments

- **Alto recorder** - Fundamental note is an F.
- **Various tubas** - Can be in B flat, F, or E flat as well as C, and may be transposing or non-transposing, depending on the piece of music, the player, and the local tradition for the instrument.
- **Trombone** - "First position" is based on the B flat harmonic series.
- **Bassoons** - Are also based on B flat; the lowest (all holes covered) note is a B flat (A on some contrabassoons).
- **Baritone and Euphonium** - These instruments are pitched in B flat, and **may or may not be treated as a transposing instrument**. Players may read either a bass clef non-transposed part, or a treble clef B flat transposed part in which the part is written a major ninth (an octave plus a whole step) higher than it is played. This curious circumstance accomodates both tuba players (who are accustomed to playing non-transposing bass clef parts) and cornet players (accustomed to playing treble clef B flat parts) who want to switch to the less-common baritone when needed.

Why are there Transposing Instruments?

Things do run more smoothly when everyone agrees on the same name for the same sound. So why are there transposing instruments? The instruments that transpose an octave have either a very high or very low range. Transposition puts their written parts comfortably in the staff and avoids using too many harder-to-read ledger lines.



Some transpositions are for the convenience of the player. Someone who has learned to play C trumpet, for example, associates a particular note with a particular fingering. If he switches to a B flat trumpet, he can use the same fingerings for the written notes, as long as the part has been appropriately transposed. If it has not (and some modern composers do not bother with transposition), he must learn to associate the same fingerings with different written notes, which can be confusing.

Other transpositions used to be for the convenience of the player, but are now mostly accidents of history. For example, there was a time when French horns, like harmonicas, came in every key, and could only play well in that key or closely related keys. French horn players could switch between different instruments playing what looked like the same set of notes, but which actually sounded in whatever key was needed. As the horn became capable of playing all notes equally well, the horn in F was the one that was chosen as having the nicest sound, so players still read parts in F.

Transposition: Changing Keys
Transposition, or changing the key of a piece of music, can be useful and is sometimes necessary to make music more singable or playable. Music is transposed by raising or lowering every note by the same interval.

Changing the key of a piece of music is called **transposing** the music. Music in a major key can be transposed to any other major key; music in a minor key can be transposed to any other minor key. (Changing a piece from minor to major or vice-versa requires many more changes than simple transposition.) A piece will also sound higher or lower once it is transposed. There are some ways to avoid having to do the transposition yourself, but learning to transpose can be very useful for performers, composers, and arrangers.

Why Transpose?

Here are the most common situations that may require you to change the key of a piece of music:

- To put it in the right key for your **vocalists**. If your singer or singers are struggling with notes that are too high or low, changing the key to put the music in their range will result in a much better performance.
- Instrumentalists may also find that a piece is **easier to play** if it is in a different key. Players of both bowed and plucked strings generally find fingerings and tuning to be easier in sharp keys, while woodwind and brass players often find flat keys more comfortable and in tune.
- Instrumentalists with **transposing instruments** will usually need any part they play to be properly transposed before they can play it. Clarinet, French horn, saxophone, trumpet, and cornet are the most common transposing instruments.

Avoiding Transposition

In some situations, you can avoid transposition, or at least avoid doing the work yourself. Some stringed instruments - guitar for example - can use a capo to play in higher keys. A good electronic keyboard will transpose for you. If your music is already stored as a computer file, there are programs

that will transpose it for you and display and print it in the new key. However, if you only have the music on paper, it may be easier to transpose it yourself than to enter it into a music program to have it transposed. So if none of these situations apply to you, it's time to learn to transpose.

> **Note:** If you play a chordal instrument (guitar, for example), you may not need to write down the transposed music. There are instructions below for transposing just the names of the chords.

How to Transpose Music

There are four steps to transposition:

1. Choose your transposition.
2. Use the correct key signature.
3. Move all the notes the correct interval.
4. Take care with your accidentals.

Step 1: Choose Your Transposition

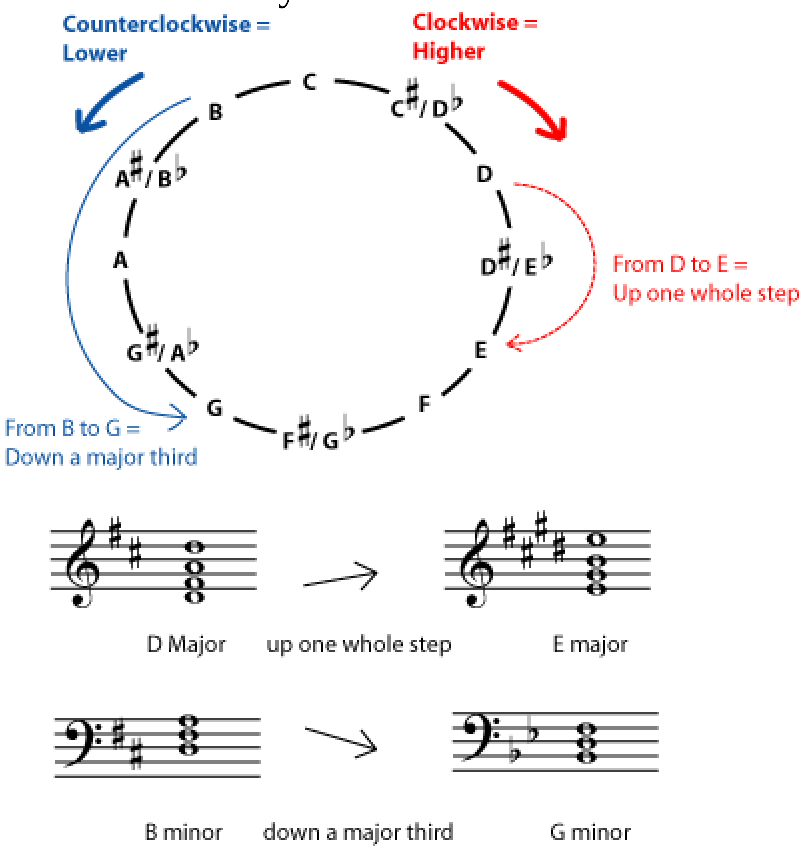
In many ways, this is the most important step, and the least straightforward. The transposition you choose will depend on why you are transposing. If you already know what transposition you need, you can go to step two. If not, please look at the relevant sections below first:

- Are you rewriting the music for a transposing instrument?
- Are you looking for a key that is in the range of your vocalist?
- Are you looking for a key that is more playable on your instrument?

Step 2: Write the New Key Signature

If you have chosen the transposition because you want a particular key, then you should already know what key signature to use. (If you don't, see Key Signature.) If you have chosen the transposition because you wanted a particular interval (say, a whole step lower or a perfect fifth higher), then the key changes by the same interval. For example, if you want to transpose a piece in D major up one whole step, the key also moves up one whole step, to E major. Transposing a piece in B minor down a major third will move the key signature down a major third to G minor. For more information on and practice identifying intervals, see Interval. For further information on how moving music up or down changes the key signature, see The Circle of Fifths.

Find the New Key

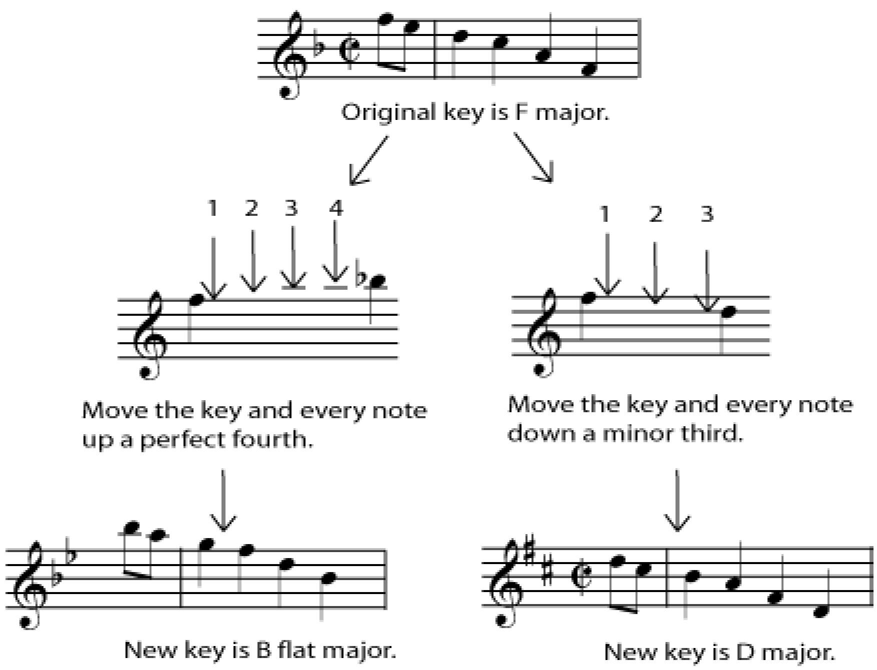


You must know the interval between the old and new keys, and you must know the new key signature. This step is very important; if you use the wrong key signature, the transposition will not work.

Step 3: Transpose the Notes

Now rewrite the music, changing all the notes by the correct interval. You can do this for all the notes in the key signature simply by counting lines and spaces. As long as your key signature is correct, you do not have to worry about whether an interval is major, minor, or perfect.

Move all the Notes



Did you move the key down a minor third? Simply move all the notes down a third in the new key; count down three lines-or-spaces to find the new spot for each note. Did you move the key up a perfect fourth? Then move all the notes up four lines-and-spaces. Remember to count every line and every space, including the ones the notes start on and end on. Once you get the hang of it, this step is very straightforward, but it may take a while if you have a lot of music.

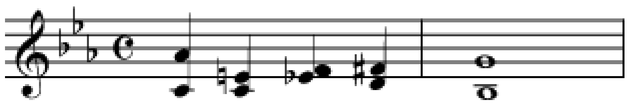
Step 4: Be Careful with Accidentals

Most notes can simply be moved the correct number of lines and spaces. Whether the interval is minor, major, or perfect will take care of itself if the correct key signature has been chosen. But some care must be taken to correctly transpose accidentals. Put the note on the line or space where it would fall if it were not an accidental, and then either lower or raise it from your new key signature. For example, an accidental B natural in the key of E flat major has been raised a half step from the note in the key (which is B flat). In transposing down to the key of D major, you need to raise the A natural in the key up a half step, to A sharp. If this is confusing, keep in mind that the interval between the old and new (transposed) notes (B natural and A sharp) must be one half step, just as it is for the notes in the key.

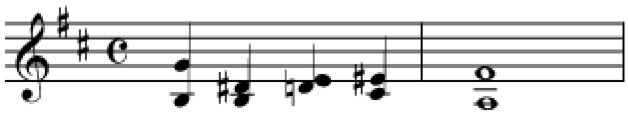
Note: If you need to raise a note which is already sharp in the key, or lower a note that is already flat, use double sharps or double flats.

Transposing Accidentals

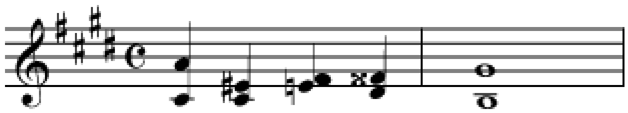
Original E flat major



Transposed to D major



Transposed to E major



Flats don't necessarily transpose as flats, or sharps as sharps. For example, if the accidental originally raised the note one half step out of the key, by turning a flat note into a natural, the new accidental may raise the note one half step out of the key by turning a natural into a sharp.

Exercise:

Problem:

The best practice for transposing is to transpose a piece you know well into a new key.

Solution:

Play the part you have transposed; your own ears will tell you where you have made mistakes.

Choosing Your New Key

Before you can begin transposing, you must decide what your new key will be. This will depend on why you are transposing, and what kinds of vocalists and instrumentalists you are working with.

Working with Vocalists

If you are trying to accomodate singers, your main concern in choosing a key is finding their range. Is the music you are working with too high or too low? Is it only a step too high, or does it need to be changed by a third or a fifth? Once you determine the interval needed, check to make certain this will be a comfortable key for your instrumentalists.

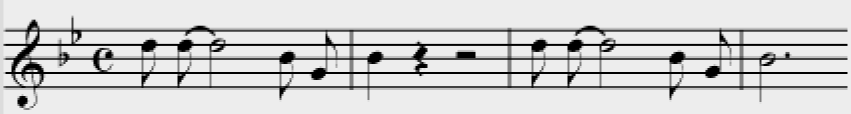
Example:
A church choir director wants to encourage the congregation to join in on a particular hymn. It is written in four parts with the melody in the soprano part, in a range slightly too high for untrained singers. The hymn is written in the key of E flat. Lowering it by a minor third (one and a half steps) will allow the congregation to sing with gusto.

The hymn is originally in E flat. The melody that goes up to an F is too high for

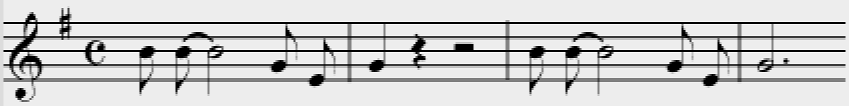
most untrained vocalists (male and female).

The same hymn in C is more easily singable by a congregation.

Example:
An alto vocalist would like to perform a blues standard originally sung by a soprano or tenor in B flat. She needs the song to be at least a whole step lower. Lowering it by a whole step would put it in the key of A flat. The guitar, bass, and harmonica players don't like to play in A flat, however, and the vocalist wouldn't mind singing even lower. So the best solution is to lower it by a minor third, and play in the key of G.



The key of this blues standard is comfortable for a soprano or tenor, as shown in this excerpt.



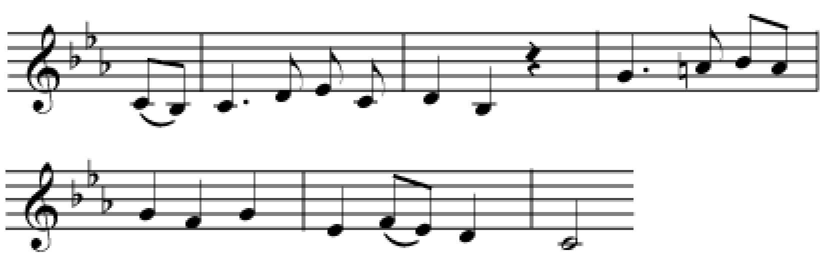
An alto or baritone can deliver a more powerful performance if the music is transposed down a minor third.

Exercise:

Problem:

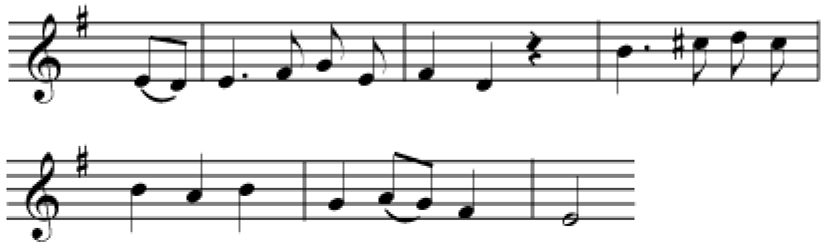
You're accompanying a soprano who feels that this folk tune in C minor is too low for her voice. The guitar player would prefer a key with no flats and not too many sharps.

Tune in C minor too low for some sopranos voices.



Solution:

Transposing up a major third, to E minor, puts the song in a better range for a soprano, with a key signature that is easy for guitars.



Moving tune up to E minor puts it in a better key for sopranos.

Transposing Instruments

Transposing instruments are instruments for which standard parts are written higher or lower than they sound. A very accomplished player of one of these instruments may be able to transpose at sight, saving you the trouble of writing out a transposed part, but most players of these instruments will need a transposed part written out for them. Here is a short list of the most common transposing instruments. For a more complete list and more information, see Transposing Instruments.

Transposing Instruments

- Clarinet is usually (but not always) a B flat instrument. Transpose C parts up one whole step for B flat instruments. (In other words, write a B flat part one whole step higher than you want it to sound.)
- Trumpet and Cornet parts can be found in both B flat and C, but players with B flat instruments will probably want a B flat (transposed) part.
- French Horn parts are usually in F these days. However, because of the instrument's history, older orchestral parts may be in any conceivable transposition, even changing transpositions in the middle of the piece. Because of this, some horn players learn to transpose at sight. Transpose C parts up a perfect fifth to be read in F.

- Alto and Baritone Saxophone are E flat instruments. Transpose parts up a major sixth for alto sax, and up an octave plus a major sixth for bari sax.
- Soprano and Tenor Saxophone are B flat instruments. Tenor sax parts are written an octave plus one step higher.

> **Note:** Why are there transposing instruments? Sometimes this makes things easier on instrumentalists; they may not have to learn different fingerings when they switch from one kind of saxophone to another, for example. Sometimes, as with piccolo, transposition centers the music in the staff (rather than above or below the staff). But often transposing instruments are a result of the history of the instrument. See the history of the French horn to find out more.

The transposition you will use for one of these instruments will depend on what type of part you have in hand, and what instrument you would like to play that part. As with any instrumental part, be aware of the range of the instrument that you are writing for. If transposing the part up a perfect fifth results in a part that is too high to be comfortable, consider transposing the part down a perfect fourth instead.

To Decide Transpositions for Transposing Instruments

1. Ask: what type of part am I transposing and what type of part do I want? Do you have a C part and want to turn it into an F part? Do you want to turn a B flat part into a C part? **Non-transposing parts are considered to be C parts.** The written key signature has nothing to do with the type of part you have; only the part's transposition from concert pitch (C part) matters for this step.
2. Find the interval between the two types of part. For example, the difference between a C and a B flat part is one whole step. The difference between an E flat part and a B flat part is a perfect fifth.
3. Make sure you are transposing in the correct direction. If you have a C part and want it to become a B flat part, for example, you must transpose **up** one whole step. This may seem counterintuitive, but

remember, **you are basically compensating for the transposition that is "built into" the instrument**. To compensate properly, always transpose by moving in the opposite direction from the change in the part names. To turn a B flat part into a C part (B flat to C = up one step), transpose the part down one whole step. To turn a B flat part into an E flat part (B flat to E flat = down a perfect fifth), transpose the part up a perfect fifth.

4. Do the correct transposition by interval, including changing the written key by the correct interval.

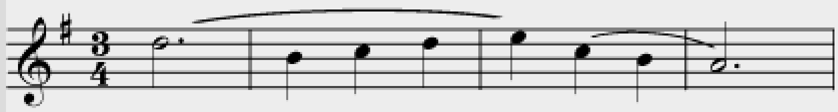
Example:

Your garage band would like to feature a solo by a friend who plays the alto sax. Your songwriter has written the solo as it sounds on his keyboard, so you have a C part. Alto sax is an E flat instrument; in other words, when he sees a C, he plays an E flat, the note a major sixth lower. To compensate for this, you must write the part a major sixth higher than your C part.

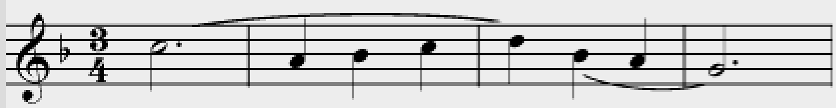
In the top line, the melody is written out in concert pitch; on the second line it has been transposed to be read by an alto saxophone. When the second line is played by an alto sax player, the result sounds like the first line.

Example:

Your choral group is performing a piece that includes an optional instrumental solo for clarinet. You have no clarinet player, but one group member plays recorder, a C instrument. Since the part is written for a B flat instrument, it is written one whole step higher than it actually sounds. To write it for a C instrument, transpose it back down one whole step.



Melody for B flat clarinet

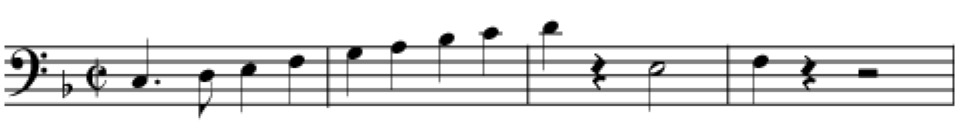


Melody transposed for C instruments

Exercise:

Problem:

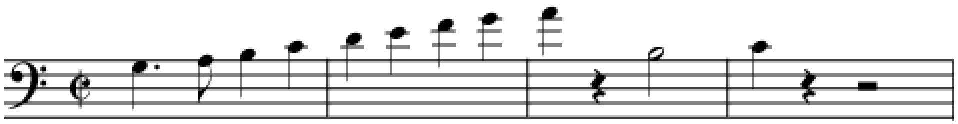
There's a march on your community orchestra's program, but the group doesn't have quite enough trombone players for a nice big march-type sound. You have extra French horn players, but they can't read bass clef C parts.



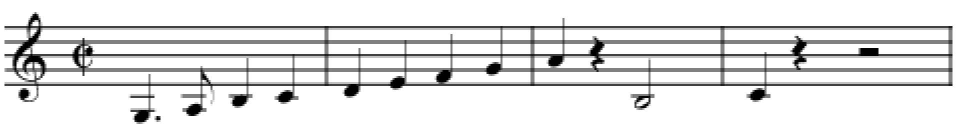
Trombone line from a march

Solution:

The trombone part is in C in bass clef; the horn players are used to reading parts in F in treble clef. Transpose the notes up a perfect fifth and write the new part in treble clef.



This is the same part transposed up a fifth so that it is in F



Now write it in treble clef to make it easy for horn players to read.

Playable Keys

Transposition can also make music easier to play for instrumentalists, and ease of playing generally translates into more satisfying performances. For example, someone writing a transcription for band of an orchestral piece may move the entire piece from a sharp key (easier for strings) to a nearby flat key (easier for winds). A guitar player, given a piece written in A flat for keyboard, will often prefer to play it in A or G, since the fingerings for chords in those keys are easier. Also, instrumentalists, like vocalists, have ranges that need to be considered.

Example:

Your eighth grade bassoon player would like to play a Mozart minuet at a school talent show with a flute-playing friend from band. The minuet is in C, but the melody is a little too low for a flute, and the bassoonist would also be more comfortable playing higher. If you transpose the whole piece up a minor third to E flat major, both players can hit the lowest notes, and you may also find that fingerings and tunings are better in the flat key.

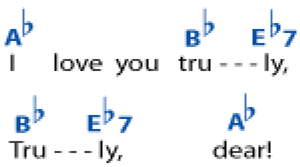
An excerpt from a Mozart Minuet in C. The upper part is too low for a flute player.

Both young instrumentalists would be more comfortable playing in this key.

Exercise:

Problem:

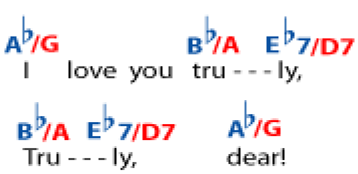
You've brought your guitar and your [capo](#) to the sing-along because you'd like to play along, too. Going through the music beforehand, you notice that your favorite song is in A flat. The pianist isn't prepared to play it in any other key, but you really don't like those thin-sounding chords in A flat. You can use your capo to raise the sound of your instrument (basically turning it into a transposing instrument in C sharp, D, D sharp, or even higher), but the less you raise it the more likely you are to still sound in tune with the piano.



Chords in the key of A flat major are not ideal for guitarists.

Solution:

Put the capo on the first fret to raise the sound by one half step. Then transpose the chords down one half step. You will be playing in G, a nice strong key for guitar, but sounding in A flat. For more on transposing chords, see [Transposing Chord Names](#)



Giving guitarists the option of playing in G

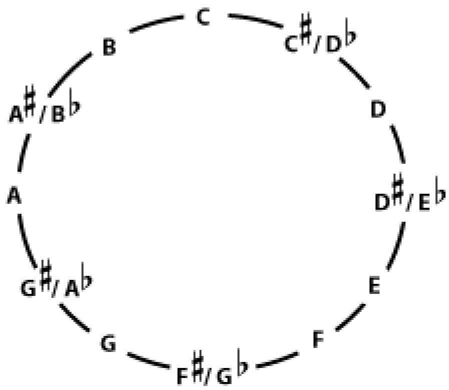
major (with a
capo) can make
things easier.

Transposing at Sight

Transposing at sight means being able to read a part written in one key while playing it in another key. Like any other performance skill, it can be learned with practice, and it is a skill that will help you become an extremely versatile instrumentalist. (Vocalists transpose at sight without even thinking about it, since they don't have to worry about different fingerings.) To practice this skill, simply start playing familiar pieces in a different key. Since you know the piece, you will recognize when you make a mistake. Start with pieces written in C, and play them only a half step or whole step lower or higher than written. When this is easy, move on to more challenging keys and larger intervals. Practice playing in an unfamiliar clef, for example bass clef if you are used to reading treble clef. Or, if you play a transposing instrument, work on being able to play C parts on sight. You may find more opportunities to play (and earn the gratitude of your fellow musicians) if you can say, "we can change keys if you like", or "I can cover that bass clef C part for you, no problem."

Transposing Chord Names

If you are transposing entire chords, and you know the name of the chord, you may find it easier to simply transpose the name of the chord rather than transposing each individual note. In fact, transposing in this way is simple enough that even a musician who can't read music can do it.
Chromatic Circle



When transposing, you can use the chromatic circle both to change the name of the key (as above) and to change chord names, because the basic idea is the same; the entire piece (chords, notes, and key) must move the same number of half steps in the same direction. If you're using a chromatic circle to transpose the names of all the chords in a piece, just make sure that you move each chord name by the same amount and in the same direction.

Step 1: Choose Your Transposition

Your choice of new key will depend on why you are transposing, but it may depend on other things, also.

- If you are transposing because the **music is too low or too high**, decide how much higher or lower you want the music to sound. If you want the music to sound higher, go around the chromatic circle in the clockwise direction. If you want it lower, go in the counterclockwise direction. The further you go, the more it will change. Notice that, since you're going in a circle, raising the music a lot eventually gives the same chords as lowering it a little (and vice-versa). If some keys are easier for you to play in than others, you may want to check to make sure the key you choose has "nice" chords. If not, try another key near it.
- If you are changing keys in order to **make the chords easy to play**, try changing the final chord so that it names an easy-to-play-in key. (Guitarists, for example, often find the keys G, D, A, E, C, Am, Em, and Dm easier to play in than other keys.) The last chord of most pieces will usually be the chord that names the key. If that doesn't seem to work for your piece, try a transposition that makes the most common chord an easy chord. Start changing the other chords by the same amount, and in the same direction, and see if you are getting mostly easy-to-play chords. While deciding on a new key, though, keep in mind that you are also making the piece higher or lower, and choose keys accordingly. A guitarist who wants to change chords without changing the pitch should lower the key (go counterclockwise on the circle) by as short a distance as possible to find a playable key. Then capo at the fret that marks the number of keys moved. For example, if you moved counterclockwise by three keys, put the capo at the third fret.
- If you are changing keys to **play with another instrumentalist** who is transposing or who is playing in a different key from you, you will need to figure out the correct transposition. For a transposing instrument, look up the correct transposition (the person playing the instrument may be able to tell you), and move all of your chords up or down by the correct number of half steps. (For example, someone playing a B flat trumpet will read parts one step - two half steps - lower than concert pitch. So to play from the same part as the trumpet

player, move all the chords counterclockwise two places.) If the instrumental part is simply written in a different key, find out what key it is in (the person playing it should be able to tell you, based on the key signature) and what key you are playing in (you may have to make a guess based on the final chord of the piece or the most common chord). Use the chromatic circle to find the direction and number of half steps to get from your key to the other key.

Step 2: Change the Names of All the Chords

Using the chromatic circle to count keys, change the note names in all of the chords by the same amount (the same number of half steps, or places in the chromatic circle) and in the same direction. Change only the note names (things like "F" and "C sharp" and "B flat"); don't change any other information about the chord (like major, minor, dim., 7, sus4, add11, etc.). If the bass note of the chord is written out as a note name, change that, also (using the same chromatic circle).

Check your transposition by playing it to see if it sounds right. If you don't like playing some of the chords in your new key, or if you have changed the key too much or not enough, try a different transposition.

Example:
Say you have a song in the key of G, which is too low for your voice. If it's just a little too low, you can go up two keys to A. If this is still too low, you can go up even further (5 keys altogether) to the key of C. Maybe that's high enough for your voice, but you no longer like the chords. If that is the case, you can go up two more keys to D. Notice that, because the keys are arranged in a circle, going up seven keys like this is the same as going down five keys.

Original Key	G	B♭	B♭6	B♭M7	E♭M7	E♭+	A7	D/A
2 keys higher	A	C	C6	C M7	F M7	F +	B7	E/B
5 keys higher	C	E♭	E♭6	E♭M7	A♭M7	A♭+	D7	G/D
7 keys higher (or 5 keys lower)	D	F	F 6	F M7	B♭M7	B♭+	E7	A/E

Example:
Now say you have a song in the key of E flat. It's not hard to sing in that key, so you don't want to go far, but you really don't like playing in E flat. You can move the song up one key to E, but you might like the chords even better if you move them down one key to D. Notice that if you are a guitar player, and everyone else really wants to stay in E flat, you can write the chords out in D and play them with a capo on the first fret; to everyone else it will sound as if you're playing in E flat.

Original Key	E♭	Gm	A♭	D♭	B♭7	B♭9	Cm	Gm
1 key higher	E	G♯m	A	D	B 7	B 9	C♯m	G♯m
1 key lower	D	F♯m	G	C	A 7	A 9	Bm	F♯m

Exercise:

Problem:

Now say that you have a song that is in B flat, which is more than a little (more than one key) too high for you. Find a key a bit lower that still has nice, easy-to-play chords for guitar.

B♭ Gm Cm7 F 7 E♭ C 9 B♭9 Gm

Solution:

The best solution here is probably to put the song in the key of G. This is three keys lower, and has easy chords.

G Em Am7 D7 C A9 G9 Em

French Horn Course Pre/Post Test

1. What type of instrument is the horn? Name three other orchestral or band instruments of the same type and give one difference between each of these instruments and the horn.
2. What does pressing a valve do to the air inside the instrument? How does that change the sound?
3. What makes the original vibrations for any horn note? What does the tubing do to the sound?
4. Why does early orchestral music have fewer horns than later music?
5. What does it mean that the horn is "in F"?
6. Why are most French horns "in F"?
7. Describe one type of horn playing that was common before valves were added to the instrument.
8. Using some staff paper (you may print a copy of this PDF file), write as many notes as you can, in the low and medium range of the instrument, that can be played with the first valve fingering. What written note is the first valve harmonic series based on? What is the concert pitch of this note?
9. Assume the music below is written in concert pitch. Transpose it so that it can be read by a French horn player, in F, and sound at concert pitch.
10. Now assume that the music below is written for Horn in F. On your staff paper, write out the music in concert pitch.